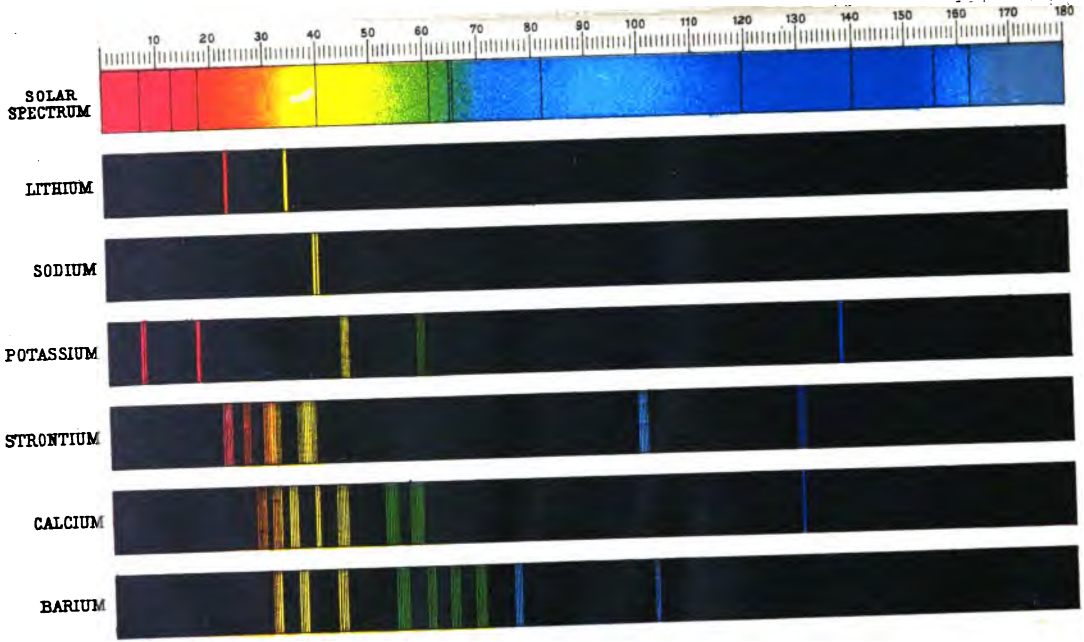
NCOTT'S

SCIENCE SERIES

NATURAL PHILOSOP

SPECTRUM ANALYSIS.



NATURAL

PHILOSOPHY.

1883

BY

ISAAC SHARPLESS, Sc.D.,
PROFESSOR OF MATHEMATICS AND ASTRONOMY IN HAVERFORD COLLEGE,

AND

GEO. MORRIS PHILIPS, Ph.D.,
PRINCIPAL OF STATE NORMAL SCHOOL, WEST CHESTER, PA.

PHILADELPHIA:
J. B. LIPPINCOTT COMPANY.

PREFACE.

This Treatise on Natural Philosophy differs from others in the large number of practical experiments and exercises which it contains. The authors believe that students of science should be, as far as possible, investigators, and, to encourage the spirit of research, they have given suggestions tending to lead them on in this way. The experiments can nearly all be performed with very simple and inexpensive materials, such as any school or home can furnish. More elaborate instruments are described for the benefit of classes which have access to them. The book can also be used by classes which have not time to perform the experiments. Yet it is strongly recommended that as many as possible be tried.

Two sizes of type are used through the book. The matter printed in large type will form a complete elementary course, and the whole book a more exhaustive one. Those who take the former are advised to include as many as convenient of the experiments, exercises, and questions. The large number given will allow the teacher to make selections suited to the ability of the class.

The use of technical terms, except where they seemed necessary to the better comprehension of the subject, has been avoided. It has been recognized that the majority

of students of natural philosophy have no use for these terms. What they want is a practical knowledge of the subject and the cultivation of scientific habits of mind.

The methods of the leading scientific men of the present time have been incorporated, and their instruments described and figured. In any treatise on the subject which embraces an account of these methods, the doctrine of the conservation of energy must have a prominent place. The great advances in practical science within the last few years, especially in sound, electricity, and meteorology, have also been utilized so far as they seem to bear on the principles.

The work has been greatly benefited by the criticisms and suggestions of C. Canby Balderston, of Westtown School, Pennsylvania. The chapters on Magnetism and Electricity were written by him.

CONTENTS.

NATURAL PHILOSOPHY.

CHAPTER I.

MATTER.

1. What is Matter?—All the bodies which occupy space, the stars and the planets, rocks, water, and air, and everything we can see or feel, are embraced under the term *matter*.

We can crumble a rock or divide a quantity of water into smaller portions. These can again be subdivided, and all the fragments will resemble the original in their properties. There is a practical limit to this subdivision, arising from the imperfection of our senses or our tools, but we may *suppose* it carried on till the very smallest possible fragments remain which possess the properties of the substance.

2. Molecules.—To these fragments we give the name molecules. They are definite quantities of matter, which have size and weight.

Hence *a molecule is the smallest portion of any substance in which its properties reside.*[1] All matter is made up of molecules. We know that molecules must be extremely small. Sixteen ounces of gold, which in the form of a cube would not measure an inch and a quarter on a side, can be spread out so that it would gild silver wire sufficient to reach around the earth. Its thickness must then be at least

---

[1] The properties of matter are those qualities which are peculiar to it,—which belong to it and to nothing else.

one molecule, and is doubtless many. In odors, which produce sensation by invisible particles, the molecules scatter about through the atmosphere for years without apparently diminishing the size of the substance from which they are separated. Microscopists have found animals so minute that four million of them would not be so large as a single grain of sand, yet each has its organs and its circulating fluids.

3. **Size of a Molecule.**—The methods of attaining an idea of the actual size of a molecule are too abstruse for explanation here, but the figures, derived from experiments of different kinds, point to $\frac{1}{500,000,000}$ of an inch as the mean diameter. This is too minute a quantity for comprehension, and may be better understood by the illustration of Sir William Thomson: "If we conceive a sphere of water of the size of a pea to be magnified to the size of the earth, each molecule being magnified to the same extent, the magnified structure would be coarser-grained than a heap of small lead shot, but less coarse-grained than a heap of cricket-balls."

The molecules of hydrogen gas are about $\frac{1}{9,000,000}$ of an inch apart, so that the spaces between are much greater than the molecules themselves.

4. **Atoms.**—When the division is carried any further than molecules, a form of matter with new properties is produced. It is not possible to divide a molecule by mechanical means, but heat or chemical agents can separate it into two or more portions. Each of these is called an *atom*. An atom cannot be further divided by any means known to us.

Hence *an atom is the smallest possible portion of matter.*

Experiment 1.—Put a piece of marble or chalk (not a crayon) into a vessel, and pour on it some good vinegar. Bubbles of gas will arise through the water.

A molecule of marble is composed of a number of atoms of different substances. The acid in the vinegar causes a division of the molecule, forming new substances. One of these substances (carbonic acid) is a gas, which passes off into the air. The others remain in the vessel.

5. **Constitution of Molecules.**—The molecules of some

substances are made up of two or more similar atoms. A molecule of hydrogen gas contains two atoms exactly alike. On the other hand, a molecule of common salt contains one atom of sodium and one of chlorine, which are widely different from each other and from salt. In their ordinary state, sodium is a soft inflammable solid, and chlorine a greenish gas. A molecule of sugar is composed of forty-five atoms of three different kinds,—carbon, which we can see as charcoal, and hydrogen and oxygen, which are colorless invisible gases.

Experiment 2.—In a vessel heat a small portion of sugar over a fire. A black substance will remain.

In this case heat effected a separation of the atoms of the molecules; the gases passed off into the air, and the solid carbon remained.

6. **Elements.**—If the molecules of a substance are composed of one kind of atoms only, it is said to be an element. Sixty-five elements have been discovered on the earth. Iron, copper, carbon, are elements. Water and air are not.

7. **Matter Indestructible.**—If the escaping gases and the carbon of the last experiment could be weighed, the sum of the weights would be found to be just equal to the weight of the original sugar. Hence we arrive at an important property of matter,—*it is indestructible.*

There are many cases of the apparent destruction of matter in combustion and chemical action, but all that is done is to change its form. The molecules are divided, and the atoms form new combinations, some or all of which are invisible. In all the various changes continually going on, in our furnaces and laboratories, and in nature, not a new atom is ever created. According to the best of our knowledge, the amount of matter in the universe has remained unchanged since the original creation.

8. **Matter Porous.**—The molecules of matter do not fit

closely together. Hence open spaces, or pores, are left between them. We then arrive at a property of matter which is believed to be universal,—*it is porous.*

Experiment 3.—Fill a tumbler with cotton-wool, pressing it down so firmly that the vessel will hold no more. Now remove the cotton and fill the vessel with alcohol. With care, the cotton may all be replaced without spilling the alcohol. The cotton has gone into the pores of the alcohol, and the alcohol into the pores of the cotton. It is impossible to conceive that the molecules of both substances occupy the same space.

9. **Matter can be Expanded and Compressed.**—As a result of the porosity of matter, it is possible to *expand* or to *compress* it. The molecules are not changed in form or size, but they are further separated in expansion, and crowded together in contraction, so that the substance becomes more porous in one case and less so in the other. Heat in general separates the molecules from one another. A ball that will just go through a ring when cold will not do so when heated. The mercury in a thermometer-tube rises in hot weather because the heat separates the molecules and there is no chance for expansion in any other direction. The ends of the rails of a railroad-track which touch each other in summer are separated in winter. A nail can be driven into wood because it causes a compression of the molecules around to make a place for it.

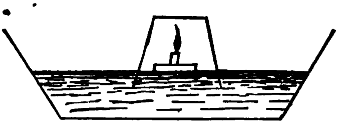


FIG. 1.—EXPANSION BY HEAT.

Experiment 4.—On a cork floating on water place a shaving. Set it on fire, and put over it an inverted tumbler. The heat of the combustion will expand the air in the tumbler and force it out under the edge; what is left will quickly cool and contract, so that almost immediately the water will rise into the tumbler.

10. **Expansion by Cold.**—Heat does not always expand bodies.

Experiment 5.—Fill a bottle with water, and cork tightly. Leave in a cold place till the water is frozen. The bottle will be cracked.

The cold here caused expansion. At 39.2° Fahrenheit a

given weight of pure water takes up least room and expands with a change of temperature either way.

11. **Some Bodies can be Hammered into Plates and Drawn into Wires.**—When certain solid bodies are hammered out into plates or drawn into wires the molecules slide past one another and arrange themselves differently. This motion of the molecules is not possible in all solid bodies, and some possess it in a much higher degree than others. Gold may be hammered out into sheets less than $\frac{1}{200,000}$ of an inch in thickness. Copper, silver, and tin can also be beaten out into very thin foil. One of the substances which may most readily be drawn out into wires is glass.

Experiment 6.—Heat in an alcohol flame, or hot gas flame, a small glass rod or tube. When red and soft, it may be drawn out into a very fine thread.

Metal wire is made by drawing the soft metal through holes, each one smaller than the preceding. Platinum wire can be reduced so that it will be finer than the finest hair.

12. **Matter Elastic.**—All bodies are more or less *elastic.* By this it is meant that when compressed within certain limits the molecules tend to come back to their original position with respect to one another.

When a ball is allowed to fall on a hard floor, there is a compression of the molecules of the ball near the point of contact with the floor. The elasticity of the ball causes an immediate restoration to the original form of the ball, and this produces the rebound. When gases are compressed, they recover their former state immediately when the pressure is withdrawn. They are said to be perfectly elastic. Although liquids can be compressed but slightly, they are also perfectly elastic.

13. **Tenacity.**—When the molecules of a solid adhere so closely that they strongly resist a force tending to pull them apart, it is said to be *tenacious.* The amount of tenacity depends on the structure of the substance.

Wrought iron, being fibrous, has much more tenacity than cast iron, which is granular. Steel is very tenacious. A bundle of wires will support much more weight than the same material in solid form. Hence the cables of suspension-bridges, which have to hold up immense weights, are usually made up of bundles of fine steel wire.

Experiment 7.—Place a piece of stick on two supports some distance apart, and break it by a weight applied in the middle. Examine the fracture. The lower fibres will be found to be separated.

14. **Bridges.**—When a weight rests on a bridge, it has to stand the same kind of strain as the stick. The tendency is to pull it apart at the bottom. Hence an iron bridge has its lower "chord" made of tenacious wrought iron rather than of cast iron. The upper chord is compressed, and as cast iron will stand more compression than wrought iron, it is frequently used there.

15. **Hardness.**—Hardness is another property of solid bodies, depending on the closeness with which the molecules stick together and resist the entrance of another body which tends to penetrate them. Hard bodies are not always tenacious. Diamond is the hardest of substances, being able to scratch everything else. This ability to scratch is the test of hardness.

Experiment 8.—Scratch a piece of glass with the edge of a quartz crystal or piece of flint. Attempt to do the same with a penknife-blade. Quartz is harder than glass, and glass is harder than steel.

16. **Density.**—There is more matter in the same space in some bodies than in others. This is either because the molecules are closer together, or because each molecule contains more matter. We express this by saying that some bodies are more *dense* than others.

17. **Volume.**—The volume of a body is the amount of space it occupies.

18. **Mass.**—The mass of a body is the quantity of matter which it contains. If a gas be heated so as to expand it, the mass remains the same, as no new molecules are formed, but the density decreases. The mass therefore depends on two things, the volume and the density. The

number of molecules in a unit (as a cubic inch) of a body multiplied by the number of cubic inches gives the whole number of molecules. In other words, the product of the volume by the density gives the mass, or

$$\text{Mass} = \text{volume} \times \text{density}.$$

19. **Unit of Length.**—The English units of length are the inch, the foot, and the yard; the French are the metre and its decimal divisions. It is convenient to remember that a metre is about 40 inches, a decimetre about 4 inches, a centimetre about $\frac{4}{10}$ of an inch, and a millimetre $\frac{1}{25}$ of an inch.[1]

20. **Unit of Surface.**—For square measure we have in English the square inch, square foot, and square yard, and in French the square metre, square decimetre, and square centimetre. The cubic units are derived in the same way.

21. **Unit of Mass.**—The unit of mass in the English system is the pound avoirdupois; in the French it is the mass of a cubic centimetre of water at its greatest density, 39.2° F. This is called a *gram*, and is about 15½ grains. This is divided and multiplied decimally for smaller and larger weights.

22. **Unit of Density.**—The unit of density for solids and liquids is the density of water at 39.2° F.

23. **Affinity, Cohesion, Attraction.**—The force which holds together the atoms in a molecule is called *affinity.*

The force which holds together the molecules in a body is called *cohesion.*

The force which holds together the different bodies of the universe is called *attraction.*

Hence affinity makes *substances;* cohesion makes *bodies;* attraction makes *systems.*

Attraction is also used to express the force which draws one body to another, as in the case of magnets, etc.

[1] The metric system possesses great advantages, especially for scientific people. Appendix I. gives it in part, and should be studied.

24. **Solids.**—In *solid* bodies the molecules preserve their positions with considerable firmness, resisting attempts to displace them. Hence these retain their form and size. The force of cohesion in them is strong.

25. **Liquids.**—In *liquid* bodies there is perfect freedom of the molecules among themselves, so that the bodies adapt their form to the surrounding vessel. They retain their size, but change their form with the slightest force exerted upon them. The force of cohesion in them is weak.

26. **Gases.**—In *gaseous* bodies there is no cohesion, the molecules have a *repellent* action upon one another, so that an unrestrained gas will expand indefinitely.

27. **Motion of Molecules.**—The molecules of all bodies are believed to be in rapid motion. In solids this is restrained by cohesion, so that a molecule has only a short vibratory motion. In liquids the molecules slide over one another without resistance, restrained only when they reach the sides of the enclosing vessel. This contact produces the pressure against the sides. In gases the molecules are strongly repelled from one another, and dash about with great velocity. Hence there are constant collisions among them and with other bodies. Our bodies are subject to this incessant battering by the little molecules of the atmosphere, but, the force being the same on both sides of the tissues, we do not notice it.

28. **Adhesion.**—Adhesion differs from cohesion in that it acts between molecules of different bodies. The force which causes mortar to stick to bricks, which causes a pencil to leave a mark on paper, which enables glues and pastes to be effective, is adhesion. It is also something like adhesion which causes water to rise in a small tube or on the side of a glass plate.

29. **Weight.**—The weight of bodies results from attraction. All bodies attract all other bodies. The more molecules a body contains, the greater is its attraction for others, and the attraction of others for it. The pull of all the particles of the earth on the objects on its surface is the same as if one strong pull drew them to its centre. Hence a

plumb-line points to the centre of the earth,[1] and different plumb-lines are not parallel, but converge downward.

30. **Gravity.** — The attraction of the earth is called *gravity.*

31. **Weight Proportional to Mass.**—The earth pulls every particle of a body. If we suppose a string attached to each molecule, and all the strings pulled by equal forces, we would have the case of attraction. Hence the more molecules the greater the attraction. But the mass is determined by the number of molecules. Hence we have the law,—

Under the same conditions the weights of bodies (or the total attractions) *are proportioned to their masses.*

32. **Weight Inversely Proportional to Square of Distance.** —The position of the body affects the weight. The attraction diminishes as the bodies recede from each other. If the distance doubles, the attraction is only one-fourth, and if the distance trebles, one-ninth, of the original amount. We express this by saying, *The attraction varies inversely as the square of the distance.*

33. **Mass Constant.**—The position of the body does not affect the mass. It might be removed far from the earth and the mass would be the same. The number of molecules—*i.e.*, the mass—would be constant if carried to the sun; but as there is so much more mass in the sun than in the earth, the attraction, and consequently the weight of the body, would be greatly increased.

34. **Unit of Weight.**—The unit of weight is the same as the unit of mass, the gram.

35. **Mobility and Inertia.**—Bodies will not move unless some force is exerted on them from without, and they yield to the slightest force impressed which is not counterbalanced by some other force. This brings us to two other

[1] This is very slightly modified by the fact that the earth is not a perfect sphere.

properties of matter,—*mobility*, which induces it to yield freely to impressed forces, and *inertia*, which prevents it from moving itself, or from changing any motion which may be given it. Matter has no power to move or to resist an unbalanced force.

Examples of inertia are numerous. It requires more force to start a car than to keep it in motion. When suddenly stopped by another force, the contents are thrown forward by their inertia. A ball projected upward stops, not because it has power to stop itself, but because another force, gravity, is constantly pulling against its motion. A marble thrown swiftly through a pane of glass will make a small round hole, because the inertia of the other parts of the glass prevents them from yielding to the sudden impression.

Experiment 9.—Place a card on the end of a finger, and a cent on the card. By a quick stroke with the forefinger of the other hand the card may be shot out, leaving the cent resting on the finger.

36. **Ether.**—We have spoken of the three forms of matter, solid, liquid, and gaseous; we have also said that the molecules of matter do not fill up the whole space, but that pores, which are large compared with the size of the molecules themselves, exist in all substances. This intermolecular space is supposed to be filled with something called *ether*, which is as far separated from gases by its properties as gases are from liquids. It also fills the pores of the air, and the spaces between the planets and between the stars, outside the bounds of the atmospheres which surround them. It is highly elastic, without weight or color, or any other properties which can be perceived by the senses. It is supposed to be the agent which by its vibratory motion conveys the rays of light from the sun to the earth, and which carries them between the molecules through transparent substances.

37. **Radiant Matter.**—Dr. William Crookes[1] has found

[1] An English scientist, now living (1883).

that by exhausting the air in a tube so as to leave not more than one-millionth the ordinary amount, the remaining substance has such peculiar properties that he feels justified in giving it a new name. He calls it *radiant matter*, and considers it to be the fourth form. Solid, liquid, gaseous, and radiant would then be the four *aggregate* states, each having properties which widely separate it from the others. By passing electric sparks through radiant matter some of its properties have been determined.[1] Of the properties of ether we know nothing by direct experiment, but it is considered likely that it is a form of radiant matter.

38. **Summary.**—Matter is made up of a countless number of minute molecules. It is perfectly inert, but each particle possesses the property of attracting every other particle. It has extension in three directions, and has three (probably four) forms of aggregation.

39. **Natural Philosophy.**—Natural Philosophy treats of the laws of cohesion, the molecular properties of matter, and the effects of the action of forces upon matter.

40. **Astronomy.**—Astronomy treats of matter in large masses, and of the laws of gravitation.

41. **Chemistry.**—Chemistry treats of the atomic properties of matter, and of the laws of affinity.

Exercises.—1. Is matter destroyed when water is dried up? when gunpowder explodes? when house gas burns? Where does it go to?

2. To what property of matter do blotting-pads owe their utility? rubber bands? watch-springs? pop-guns? putty? hammers? piano-strings? water-filters?

3. Why does not the addition of a little sugar to a full cup of coffee cause it to overflow?

4. When we fix the head of a hammer on the handle by striking the end of the handle on a block, what property do we use?

5. Why does a foot-ball, nearly empty, become full when we exhaust the air from around it? why does it soon collapse?

6. One sixteen-thousandth of a cubic inch of indigo dissolved in sulphuric acid can color two gallons of water. What property of matter is here shown?

7. How would you test the relative hardness of two minerals?

[1] These will be further explained, page 314.

8. When water is converted into steam, are the molecules enlarged or separated? is its mass increased or diminished? its density? its weight? its volume?

9. Name a substance which is often found in all three forms.

10. If you knew the volume and mass of a solid, how would you obtain its density? if you knew its mass and density, how would you obtain its volume?

11. Give an instance of a hard body which has little cohesion.

12. Why does not a large stone fall to the earth more rapidly than a small one?

13. If a body were removed to a distance of 8000 miles from the surface of the earth, how much less would it weigh than at the surface? *Ans.* $\frac{1}{9}$ as much.

14. What would a 100-pound weight weigh if moved to the distance of the moon (60 radii of the earth)? *Ans.* $\frac{1}{36}$ pound.

15. Suppose a sphere were one-half the diameter of the earth and of the same density, what would a body which weighed 100 pounds on the earth weigh at its surface? *Ans.* 50 pounds.

Note.—Its mass would be one-eighth that of the earth, and distance of the body from its centre one-half.

CHAPTER II.

MOTION AND FORCE.

42. **Rest and Motion.**—A body is at *rest* when it does not change its place. It is in *motion* when it does change its place.

No body with which we are acquainted is at rest. The earth and all that is on it move with great velocity. The sun moves, and so do the stars. But when a book lies on the table it does not move with respect to the surrounding bodies or the earth. It is at *relative* rest, but in absolute motion.

43. **Kinds of Motion.**—When a body in motion passes over equal spaces in equal times, its motion is *uniform.* When it passes over unequal spaces in equal times, its motion is *varied.* When the spaces in successive times become greater, its motion is *accelerated*, and when less, *retarded.* This acceleration or retardation may also be uniform or varied.

44. **Velocity.**—The *velocity* of a motion is the space traversed in the unit of time. It may be in miles per hour, feet per second, etc.

Feet moved in Successive Seconds.				Kinds of Motion.
30	30	30	30	Uniform.
10	15	20	25	Uniformly accelerated.
20	18	16	14	Uniformly retarded.
20	14	16	4	Varied,—not uniformly.

Questions.—When a train starts from a station, what kind of motion is it? when stopping? when a ball is thrown upward? when it falls? What kind of motion in the hands of a watch? in the current of a river? in the winds?

45. **Force.**—*Force is anything which tends to produce, change,*

or destroy motion. If it acts on a body at rest, it produces motion. If it acts on a body in motion, it may change the direction or velocity of the motion, or destroy it. Two or more forces may act on a body at rest so as to balance each other and cause no motion. But each one *tends* to produce motion. In bridges and buildings we have cases of balanced forces. Gravity is a force always acting upon them, and upon everything they sustain. This produces other forces acting along the various timbers and pieces. If the structure is well built, the strains from these forces are exactly balanced, every part is sufficiently strong to do its work, and there is no motion except such as is due to the elasticity of the materials.

46. **Kinds of Force.**—A force may act for an instant and then cease, in which case it is said to be an *impulsive* force; or it may act for some time, when it is a *continuous* force. The striking of a ball by a bat is an example of an impulsive force, and the pulling of a train by a locomotive, of a continuous force.

47. **Impulsive Force produces Uniform Motion.**—*An impulsive force tends to produce uniform motion, and a continuous force accelerated motion.* This would seem to be contradicted by experience. For the motion of a ball is soon destroyed, and the continual pull of the engine may only keep the train moving uniformly. But the force of the bat or of the locomotive does not act alone. Were it not for gravity, the resistance of the air, and friction, which are modifying forces, the ball would move on forever with uniform velocity, and the velocity of the train would be accelerated so long as the engine pulled it ever so slightly.

48. **Newton's Laws of Motion.**—All the circumstances of motion are embraced in three laws, first enunciated by Sir Isaac Newton. These cannot be proved mathematically. They should be looked upon as fundamental principles, which depend on the properties of matter, and which may be shown to be true by experiment.

1. *A body at rest remains at rest, and a body in motion continues to move forward in a straight line, until acted on by force external to it.*

2. *Motion or change of motion is proportional to the force impressed, and is in the straight line in which the force acts.*

3. *When bodies act on each other, action and reaction are equal and in opposite directions.*

The first law is the result of the inertia of matter, and the second, of its mobility. The first says matter can do nothing itself, and the second, that the slightest force will have its corresponding effect.

The third law may be made clear by some illustrations. The earth attracts an apple and causes it to fall. The apple attracts the earth just as strongly, and the earth moves to meet it, but the greater mass of the earth makes it move so little that the motion is not noticed. When you hold up a body in your hand, the hand presses up just as hard as the body presses down. The reaction of the water on the oar, and on the fins of a fish, causes the boat or the fish to advance; the reaction of the air on the wings causes the bird to sustain itself and to move forward.

49. **Momentum.**—*Momentum is the quantity of motion.* The momentum of the earth *was the same as the momentum of the apple.* For while its *velocity* was less, its *mass* was as many times greater. Hence mass and velocity together make up momentum. A body weighing two pounds has twice the motion of one of one pound which has the same velocity; a body with twice the velocity of another has twice the motion, the mass being the same. In general we have the equation,—

$$\text{Momentum} = \text{mass} \times \text{velocity}.$$

50. **Measure of Forces.**—We may measure forces in two ways. One way is by the pressure necessary to resist them,—weighing the forces, as it were. The unit would then be in the English system the pound, and in the French system the gram. These would vary as gravity varied,

being greater nearer the level of the sea. A better way to measure forces is by the velocity they would produce. We have here also two systems.

In the English, the unit of force is the force which, acting for one second, will cause a pound of matter to have a velocity of a foot a second.

In the French, it is the force which, acting for one second, will cause a gram of matter to have a velocity of a centimetre a second. This unit is called the *dyne* (pronounced *dine*), and is coming into general use among scientific men.

51. **Acceleration.**—The velocity which a force would produce in a unit of mass in a second is called its *acceleration*.

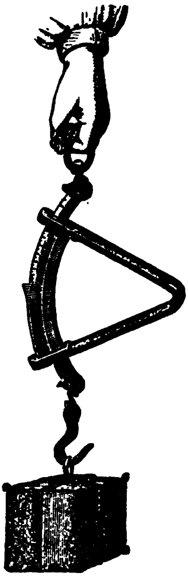


FIG. 2.—DYNAMOMETER.

52. **Illustrations.**—We will now illustrate some of these terms. If a body weighing 20 grams has a velocity of 10 centimetres a second, its momentum is 200. (This is not foot-pounds or grams or centimetres; the unit of momentum has no name.)

If this momentum is produced by a force acting for 1 second, it is a force of 200 dynes; if for 5 seconds, it is a force of 40 dynes.

53. **Acceleration a Measure of Force.**—If a force acting on the body for 1 second will give it a velocity of 10 centimetres, the acceleration is 10. During every succeeding second which it acts, it adds 10 centimetres to its velocity. As its inertia keeps the body moving at its former velocity, this continual force constantly increases its velocity. The greater the force, the greater will be the velocity produced the first second. *The acceleration is a measure of the force.*

54. **Dynamometer.**—A practical way of measuring some

forces is by a spring-balance placed in the line through which the force must act. A dynamometer (Fig. 2) is an instrument of the same kind, registering the amount of force expended. It is used to determine the resistance to motion of a train, wagon, plough, or other instrument.

If a body be hung on a spring-balance, we weigh the force of gravity. If a spring-balance or dynamometer is placed between a horse and a plough, we weigh in the same manner the force of the pull of the horse. If the horse pulls with a force of 200 pounds, this means that the connection with the plough is strained just as a rope would be if sustaining a weight of 200 pounds.

Questions.—1. What kind of force is gravity? what kind of force drives the bullet from the gun? what kinds of motion would they produce if unmodified?

2. Which of Newton's laws are illustrated by the breaking of an egg against a table? by the tendency of a train to be thrown outward over a curve? in the throwing of a ball? in the fact that it is more difficult to start a train than to keep it in motion?

3. A body weighing 20 pounds has a momentum of 400: what is its velocity in feet per second?

4. Two bodies, one of 20 and one of 2 pounds, are drawn together by their mutual attractions: which will move the faster, and how much?

5. A body of 20 grams and a velocity of 10 centimetres per second meets another body of 40 grams moving in the opposite direction with a velocity of 4 centimetres per second: in what direction will the bodies move after impact? *Ans.* In the direction of the first.

6. How many dynes of force are required to produce a velocity of 500 centimetres per second in a body of 200 grams weight in 5 seconds? *Ans.* 20,000.

7. What would be the mass if 20 dynes of force would produce in 5 seconds a velocity of 5 centimetres per second? *Ans.* 20.

8. In how many seconds would a force of 40 dynes produce a momentum of 400 units? *Ans.* 10.

55. Representation of Forces.—A force may be represented by a straight line. Thus, the line *ab*

indicates that the force acts on a body at *a* in the direction *ab*. The length of the line may also represent the magnitude of the force. A line twice as long would represent twice as great a force.

56. Resultant.—The *resultant* of two or more forces is the name given to a single force which would produce the same effects.

If two forces, one of 2 pounds and one of 4, act on a

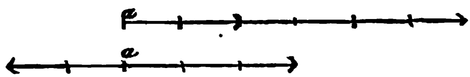


FIG. 3.—FORCES IN A LINE.

body at *a* in the same direction, their resultant is evidently a force of 6 pounds acting in the same direction. If they act in opposite directions, their resultant is the difference of their forces (2 pounds), and acts in the direction of the greater. By considering one direction as positive and the other as negative, we express both of these cases by a single law.

57. Resultant of Parallel Forces.—*The resultant of two or more parallel forces is their algebraic sum.*

If in one direction we have forces of 6, 2, 4, and in the other 3, 7, 1, the resultant is $6 + 2 + 4 - 3 - 7 - 1 = +1$. The resultant is 1, and acts in the direction of the plus forces.

58. Parallelogram of Forces.—If the forces do not act in the same line, they may still have a single resultant.

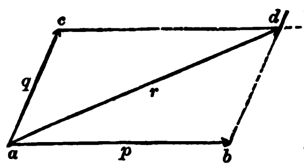


FIG. 4.—PARALLELOGRAM OF FORCES.

Let the forces *p* and *q* act on *a* at the same time in the directions given in the figure. According to Newton's second law, each of the forces would have its full effect on the body. The force *p* would carry it somewhere in the line *ab*, but the force *q* is such as to take it over the space *ac*. Hence it would bring it into the line *cd*, parallel to *ab*. By the same reasoning the body would be shown to be brought into the line *bd*, parallel to *ac*. If it is brought into both of these

lines it must be brought to their place of meeting at *d*. The figure *abdc* is a parallelogram, and is called in this case the *parallelogram of forces*. The body would move in a straight line, *ad*, which is the diagonal of the parallelogram, and its motion would be the same as if acted on by the single force *r*. Hence *r* is the *resultant* of *p* and *q*.

59. **Triangle of Forces.**—If we consider the forces without reference to their point of application, *ab*, *bd*, and *ad* will represent them, and will form a triangle. A force acting at *a*, equal and opposite to *ad*, will balance *ad*. Hence the three forces *ab*, *bd*, and *da* (notice the order of the letters) will form a system which is balanced. We have a general truth that if three forces are represented in magnitude and direction by the sides of a triangle taken in order, the system is balanced.

60. **Resultant of any Number of Forces.**—If more than two forces act on one point, we must find the resultant of two of them; then of this resultant and a third force; and so on.

If *ab*, *ac*, *ad*, and *ae* are forces acting at *a*, then the resultant of *ab* and *ac* is *ar*; of *ar* and *ad*, *ar′*; and of *ar′* and *ae*, *ar″*. It will be observed that *abrr′r″* is a polygon, four of the sides of which are parallel to the forces, and the fifth represents the resultant.

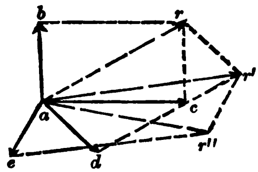


FIG. 5.—POLYGON OF FORCES.

61. **Polygon of Forces.**—This principle is called the *polygon of forces*, and may be stated as follows: If a figure be constructed having the sides equal and parallel to the forces, the line necessary to close this polygon, drawn from the starting-point, will represent the magnitude and direction of the resultant.

Also, if the forces acting on a body be represented in magnitude and direction by the sides of a polygon taken in order, the system is balanced.

62. Forces not in a Plane.—If the forces are not all in one plane, the method would produce the outlines of a solid body.

If *ab*, *ac*, *ad* be three forces not in one plane, *ar* is the resultant of the first two, and *ar′* the final resultant.[1]

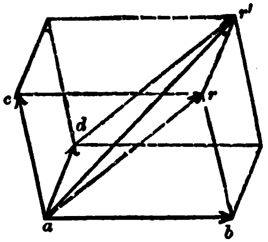


FIG. 6.—PARALLELOPIPED OF FORCES.

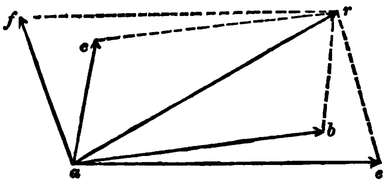


FIG. 7.—RESOLUTION OF FORCES.

63. Composition and Resolution.—The force *ar* may be divided into two forces, *ab* and *ac*, or into *ae* and *af*, or, in general, into any two which with it would make a triangle.

Combining forces so as to get a resultant is called the *composition of forces*, and separating single forces into several parts is called the *resolution of forces*. The parts are called *components*.

Experiment 10.—Fasten two pulleys against a vertical board so that they will turn freely. Arrange cords as in the figure, making the knot at *a* so as not to slip. Hang weights *p*, *q*, and *r*, being careful not to get *r* greater than *p* and *q* combined. Measure off *ab* and *ac* proportional to the weights *p* and *q*, and draw lines on the board to complete the parallelogram *abdc*. Measure *ad*, and it will be found to be equal to *r* on the same scale that *ab* and *ac* were made; also the point *d* will be found to be directly over *a*.

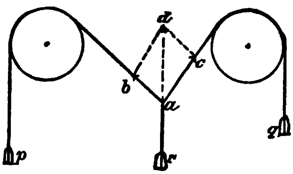


FIG. 8.—RESOLUTION OF FORCES.

This shows that the diagonal *ad* represents the resultant in magnitude and direction.

[1] If the forces do not all act on the same point in the body the problem becomes too complex for this treatise.

Experiment 11.—Place spring balances in the strings between *a* and the pulleys, and measure the forces in this way.

64. **Rowing across a Current.**—If a man undertakes to row straight across a river in which there is a current, his course will be oblique. For let *ab* represent the force of his rowing, and *ac* the force of the current. Then the resultant *ad* will be the direction of his course, and he will land at *f* instead of at *e*. If he wants to go straight across, he will steer in the direction *a'b'*, so that *a'b'* combined with *a'c'* will have a resultant in the direction *a'e'*.

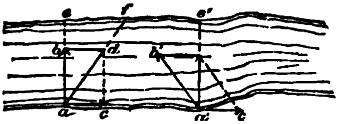


FIG. 9.—CROSSING A CURRENT.

65. **Sailing a Boat.**—In sailing a boat we have a good illustration of the resolution of forces. Let *ab* be the keel, *cd* the direction of the sail, and *fe* the force of the wind. *fe* may be resolved into two forces, *fg*, parallel to the sail, which would have no effect in driving the vessel forward, and *ge*, perpendicular to it. The force *ge* may again be resolved into *gh*, perpendicular to the keel, and *he*, in its direction. This latter force is all that is effective in propelling the boat. The force *gh* tends to upset it. In a complete analysis of forces the action of the rudder must also be taken into account.

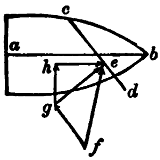


FIG. 10.—SAILING A BOAT.

66. **Component Forces greater than the Original.**—It is possible to resolve a force into two components each of which shall be much greater than the original force. If in Fig. 8 the weight *r* should be very small, the line between the pulleys would be nearly straight, and by constructing the parallelogram it would be seen that the components along *ab* and *ac* would be much greater than *r*. The same principle is shown in the knee-joint (Fig. 11). This consists of a pair of levers, jointed together at *b*. One of them is

firmly fixed at the end *a*, the other is attached to a movable slide. Any force, *p*, acting vertically on the joint will be resolved into two, one along each lever. The more obtuse the angle at the joint, the greater will be the component forces as compared with the applied force.

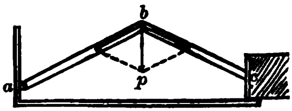


FIG. 11.—KNEE-JOINT.

Experiment 12.—Stretch a string tightly between two fastenings. Tie a weaker string to its middle point. By pulling this the stronger string breaks first. For the component pull is stronger than the original.

67. **Centrifugal Force.**—When a body is swung around by a string there are two forces acting on it. One is its inertia, which would tend to cause it to move in a line, *ab*, touching the curve. The other is *ac*, the pull of the string. The tendency would be to move in the diagonal *ad*. But as this pull is acting continuously, and the direction continually changing, the line is a curve. These are the forces which keep the earth and all the planets in their orbits.

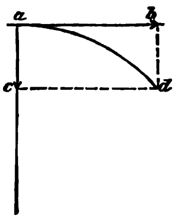


FIG. 12.—MOTION IN A CURVE.

The outward pull on a string, which is the result of the inertia of the body tending to cause it to get farther from the centre, is *centrifugal force*. It is always opposite and equal to the force drawing towards the centre.

68. **Centrifugal Force Apparatus.**—Its effect is shown in the centrifugal force apparatus of Fig. 13. Here the flexible bands are put in rapid rotation, and the centrifugal force makes them assume the form indicated by the dotted line.

69. **Effects of Centrifugal Force.**—There are many other illustrations of centrifugal force. When the earth was a soft body, the centrifugal force caused by its rotation on its axis probably produced the bulging at the equator which we now notice. The centrifugal force is greater at the equator

than elsewhere, because of the greater velocity of the earth there. Hence bodies are lighter there than at the poles. An equestrian leans inward in riding around a curve, to

FIG. 13.—CENTRIFUGAL FORCE APPARATUS.

balance the centrifugal force. It is this force which causes mud to fly off moving carriage-wheels, or water from a grindstone, and which sometimes breaks a rapidly-revolving fly-wheel. In sugar-refineries the syrup is separated from the crystals by being thrown outward, the sugar being retained by a wire gauze. Clothes are dried by a similar arrangement. In a bicycle in motion the centrifugal force causes the particles to continue to move in the same plane. Hence the faster it is going the more difficult it is to overturn.

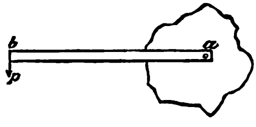


FIG. 14.—MOMENT OF A FORCE.

70. **Moment of a Force.**—The moment of a force is its ability to produce rotation. If *bc* be a lever attached to a body which has power to rotate about an axis at *a*, and a

force be applied at b, in the direction of the arrow-head, it will tend to produce rotation. This ability will depend on the magnitude of the force and the length of its lever-arm, and is equal to their product. Thus, the moment of $p = p \times ab$.

1. A force of 10 pounds has a lever-arm of 2 feet: what is its moment?

Ans.—20 foot-pounds.

2. A force of 16 grams has a lever-arm of 200 metres: what is its moment in kilogram-metres?

If a man attempt to overturn a heavy pillar, he will push against it some distance above the base; for in this case his lever-arm will be greater, and consequently the moment of the force which he exerts. It is familiar to every one how much is gained by a long lever in producing an effect; that this effect is increased not only by increasing the force, but also by increasing the length of the arm through which it acts. Seeing that this was the case, Archimedes is reported to have said that with a lever long enough he could move the world.

Exercises.—1. A current flows east at the rate of 4 miles an hour, and a vessel heads north at the rate of 10 miles an hour: draw a diagram showing the true direction and velocity of the vessel.

2. Four men pull at a rope with forces of 40, 50, 25, and 60 pounds in the same direction: what is the resultant pull? If the two latter pull in an opposite direction from the others, what is the intensity and direction of the resultant?

3. Two men carry a basket; one pulls upward with a force of 20 pounds, and the other with a force of 40 pounds: what is their resultant and the weight of the basket?

4. A body is given simultaneously three blows, one eastward at the rate of 40 feet per second, one northward, 28 feet per second, one westward, 32 feet per second: which way does it move, and with what velocity?

71. **Work.**—Work consists in moving against resistance. A horse or an engine does work when it pulls a load, a bird when it propels itself through the air, a man when he lifts up a weight.

Let us take the latter case. When a load is lifted, a cer-

tain amount of work is done; when it is lifted twice as high, twice as much work is done, or when the weight is twice as great, twice as much work is done; when twice as great a weight is lifted through three times the height, six times the work is done; or,

$$\text{Work done} = \text{weight} \times \text{height}.$$

In general, the work done by any force is the product of the force and the distance through which the point of application is moved.

72. **Unit of Work.**—A unit of work is the work done in raising a unit of weight through a unit of height. In the English system the units are the foot and the pound, and the unit of work is called the *foot-pound;* in the French system the kilogram and metre are used, and the unit of work is the *kilogram-metre.*

73. **Horse-Power.**—For large engines a larger unit is used, the *horse-power.* This is equivalent to 33,000 foot-pounds per minute.[1] An engine capable of lifting 33,000 pounds 1 foot in 1 minute, or 66,000 pounds 1 foot in 2 minutes, or 11,000 pounds 6 feet in 2 minutes, is an engine of 1 horse-power. Multiply weight in pounds by height in feet, divide by the number of minutes and by 33,000, and we have the horse-power.

74. **Erg.**—As these units depend on gravity, which is variable, another, based on the French system, has been employed, called the *erg;* the *erg* is the work done by a force of one dyne acting through one centimetre.

Exercises.—1. How many foot-pounds of work are done in lifting 20 pounds through 10 feet? how many kilogram-metres?

2. An engine can lift 2 tons 20 feet in 40 seconds: what is its horse-power?

3. An engine can lift 20 kilograms 20 metres in 20 seconds: what is its horse-power?

4. How many ergs of work are done by a force of one dyne acting through a metre?

5. A force gives to a decagram of matter a velocity of 2 centimetres

[1] The element of time enters into *horse-power*, but not into *foot-pounds.*

a second. If this force acts through a metre, how many ergs of work are done?

75. **Energy.**—*Energy is ability to do work.* A moving body has this ability, hence it has energy. A body lifted up has this ability, hence it has energy. The units of energy are the same as the units of work.

76. **Potential Energy.**—A weight held up by the hand has the power by virtue of its position to fall, and hence do work, if its support be withdrawn. A body of water held up by a dam has the power to do work on a water-wheel, if allowed to fall upon it. A wound-up spring has power to perform work in turning the machinery of a clock. This kind of energy is called *energy of position*, or *potential energy.*

77. **Actual Energy.**—A weight descending, water falling on a wheel, a spring uncoiling, a bullet moving through the air, a muscle in use, have energy,—*energy of motion*, or *actual energy.*

78. **Formula for Potential Energy.**—The formula for potential energy is $w \times h$, where w represents the weight of a body, and h the height to which it is raised. For it is evident that increasing either of these quantities will proportionately increase the ability of the body to do work.

79. **Formula for Actual Energy.**—The formula for actual energy is $\frac{1}{2}mv^2$, where m represents the mass, and v the velocity of the moving body. For its momentum is mv (Art. 49). Now, suppose it to be moving against a resistance which takes one unit from its momentum each second, it will then require mv seconds to bring it to rest, and its mean velocity will be $\frac{1}{2}v$, for it diminishes uniformly from v to nothing. The distance through which the body would move is $mv \times \frac{1}{2}v = \frac{1}{2}mv^2$. It therefore does $\frac{1}{2}mv^2$ units of work upon the resistance (for the resistance is supposed to be a unit of force), and its actual energy is $\frac{1}{2}mv^2$.

80. **Energy of a Projectile.**—When a ball is thrown upward, its energy of motion becomes gradually less and less, and its energy of position greater and greater. At its highest point the one is nothing, the other is the greatest possible. During the fall the conditions are reversed. We

say that the energy of motion is converted into energy of position in the ascent, and converted back in the descent.

81. **Potential and Actual Energy equal.**—We have proved the two formulæ,—

$$\text{Potential Energy} = wh.$$
$$\text{Actual Energy} = \tfrac{1}{2}mv^2.$$

In the section on falling bodies we will prove other formulæ, which will show that the energy of motion which a body has at the beginning of its ascent is just equal to the energy of position at its highest point; that is, that under these conditions $wh = \frac{1}{2}mv^2$.

82. **Conservation of Energy.**—This brings us to the very important doctrine of the *conservation of energy*. This says that energy is always conserved or preserved; that it is never destroyed, but may be converted into energy of another form; that the sum of the energies of the universe, like the sum of the matter of the universe, is constant; that energy is indestructible, as matter is. We cannot follow energy through all its transformations, any more than we can follow matter, but we have the best of grounds for believing in the truth of the theory.

We will show in future chapters that heat, light, and electricity are motions of the particles of bodies or of the ether; hence we have other forms of energy in them. These are all convertible, without loss, into one another and into the two forms mentioned above. When a nail is struck by a hammer, it becomes hot, for the force of the blow is changed into heat, and sometimes, when sparks are struck, into light. When water falls on a wheel from a pond, its energy of position, first converted into energy of motion, moves the wheel; but part of this energy produces heat by striking the wheel, part produces heat in the bearings, and part runs the machinery. If an electrical machine be connected with it, some of the energy will be converted into electricity with its attendant light.

In a steam-engine the energy of position of the molecules of coal is converted into heat, and the heat finally into motion of the piston.

83. **Correlation and Conservation.**—The principle that one force can be converted into another is the *correlation of forces*, while the principle that in this correlation no energy is lost is the *conservation of energy*. These are long names, but they express truths which are of great importance in modern science, and should be thoroughly understood.

Exercises.—1. How many foot-pounds of energy of position has a weight of 20 pounds 8 feet above the floor, with respect to the floor? a table 3 feet high stands on the floor: how much has the weight with respect to this table? *Ans.* 160, 100.

2. A bullet of 1 ounce is shot from a 20-pound gun with a velocity of 1600 feet per second: has the motion of the bullet or the recoil of the gun greater energy? and how much?

Note.—Because the momentum of the bullet equals the momentum of the gun,

$$1600 \times \tfrac{1}{16} = 20 \times \text{velocity of recoil.}$$

$$\text{Velocity of recoil} = 5 \text{ feet per second.}$$

$$\text{Energy of motion} = \tfrac{1}{2}\, mv^2 = \tfrac{1}{2}\, \frac{W}{g} v^2.$$

$$\text{For the bullet} = \tfrac{1}{2} \times \frac{\tfrac{1}{16}}{32.2} \times (1600)^2 = 2484. +.$$

$$\text{For the gun} = \tfrac{1}{2} \times \frac{20}{32.2} \times 5^2 = 7.7 +.$$

Note.—From this we see the difference between momentum and energy. It is the energy, not the momentum, which gives the power to the ball to penetrate bodies and to do harm. As we increase the velocity, we increase the momentum in the same proportion, but we increase the energy in the square ratio. As velocity is doubled, momentum is doubled, but energy is quadrupled. As velocity is trebled, momentum is trebled, but energy is increased ninefold.

Perhaps we can understand this better if we consider that as it goes twice as fast it will meet twice as many particles in the same time, and it will crowd them away twice as fast; that is, it has four times the effect; if it has three times the velocity, it will have nine times the effect; and so on.

3. State what transformations of energy take place in sliding a body down a plane, in the electric light, in ringing a bell, in lighting a match, in a clock running down, in a pendulum swinging.

4. Which would be preferable, to carry a 40-pound trunk up 20 feet or a 60-pound trunk up 15 feet?

5. How many pounds of water per minute will a 20 horse-power engine raise through 200 feet? *Ans.* 3300.

GRAVITY AND STABILITY.

84. **Effects of Attraction.**—The earth attracts every particle of matter towards itself. This gives us the phenomena of falling bodies, causes matter to have weight, makes the surface of still water level, and constantly operates in many ways we do not notice.

85. **How Attraction Acts.**—It does not require any time for this force to act. Attraction traverses the great space between the sun and the earth, to the best of our knowledge, instantaneously. Nor does the interposition of another body affect it in any way. We can cut off sound or heat or light by the interposition of a wall, but attraction acts through it without diminution. Nor does the kind of matter make any difference. Every molecule is attracted alike, the number of molecules determining the total attraction.

86. **Law of Attraction.**—The law of gravity, which was discovered by Newton, is that *every portion of matter in the universe attracts every other portion with a force directly proportional to the masses, and inversely proportional to the square of the distance between them.*

Questions.—How much is the attraction between two masses changed by doubling the distance between them? by increasing it 5 times? by doubling one mass? by doubling one mass, trebling the other, and trebling the distance between them?

87. **Decrease of Gravity Downward.**—The gravity is greatest at the surface of the earth. When we go down into the earth the gravity decreases, because some of the matter of the earth is attracting us upward. Were we to get half-way to the centre we should only have half the weight that we have at the surface. At the centre we should have no weight, being equally attracted in all directions.

Were it possible for a body to fall freely towards the centre, it would increase its velocity continually and fly to the surface on the other side, thence back again. Were there no resistance, this would go on forever. Otherwise,

the vibrations would become smaller and smaller, and the body would finally settle at the centre.

88. **Centre of Gravity.**—The centre of gravity of a body is the point about which it will balance in every position. If a body has a uniform figure and the same structure throughout, the centre of gravity is in the centre of the figure, and is readily found. The centre of gravity of a homogeneous sphere is at its centre; of a cylinder, at the centre of its axis; of a uniform ring, not in the mass of the ring, but in the space in the centre; of a rectangular block, where its diagonals intersect.

89. **How to find the Centre of Gravity.**—If a body is hung up by a string, the centre of gravity will be in the line of the string prolonged downward. If a new point of suspension be taken, and the line prolonged downward, it will cut the first line in the centre of gravity. This enables us to find the centre of gravity in certain cases. In the case of a thin body, we may balance it over a ruler in two directions, or over the edge of a table, as in Fig. 17. If the lines of the ruler or the edge of the table be marked on it, their intersection will be the centre of gravity. In general, its position has to be found mathematically.

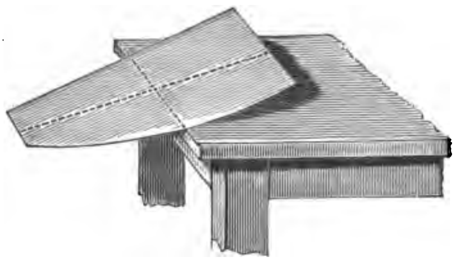


FIG. 17.—CENTRE OF GRAVITY.

Experiment 13.—Lay a thin board on a ruler, and find its centre of gravity as described. Bore a hole here and insert an awl. Notice how the board is balanced in every position.

Experiment 14.—Bore a hole in a board, and insert an awl, on which hang a plumb-line. Mark the path of the line on the board. Do this again from some other point. The intersection of the lines is the centre of gravity.

90. **Representation of Weight as a Force.**—A line down-

ward from the centre of gravity of a body may represent its weight; that is, it will be the resultant of all the parallel pulls of the earth on its different particles. Hence in treating of the weight of a body as a force we must represent it by a line, in the direction of a plumb-line, downward from its centre of gravity.

91. **Base of Support and Centre of Gravity.**—If a body rests on a support, and a line from the centre of gravity downward meets this support within the base of the body, it will remain in position; if not, it will slide or overturn, for the downward pull meets with no resistance.

Experiment 15.—Find the centre of a board, as in Experiment 14. Tilt it sidewise, and notice that when the centre is exactly over the

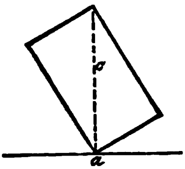


FIG. 18.—CENTRE OF GRAVITY AND BASE OF SUPPORT.

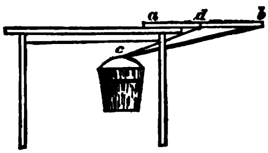


FIG. 19.—CENTRE OF GRAVITY.

point of support *a*, as indicated by a plumb-line, the body is just ready to turn either way.

Experiment 16.—Place a light piece of stick, *ab*, with one end resting on a table. At *b* notch it so that another stick, *bc*, may fit in the notch and press against the handle of a bucket under the table. A string, *cd*, must also be attached to the handle. A great weight may now be placed in the bucket, for the centre of gravity of the weight comes under the support at *a*. If *b* is depressed, it raises the centre of gravity, and hence *b* is again quickly raised.

A wagon at rest will overturn when the line drawn from the centre of gravity falls outside the wheels. The tower of Pisa[1] could be made to overturn by building it higher, for the centre of gravity would thus be thrown farther out.

When a man stands erect, the line from his centre of

[1] Where is this, and how constructed?

gravity falls between his feet. In beginning to walk, he throws his body forward, so as to bring his centre of gravity

FIG. 20.—LINE FROM CENTRE OF GRAVITY MUST FALL INSIDE THE WHEELS.

in front of his feet. He would now fall did he not catch himself by throwing one foot forward. The operation is then repeated with the other foot. He also throws his body from side to side, so as to keep the centre of gravity over the foot which is on the ground. In carrying a

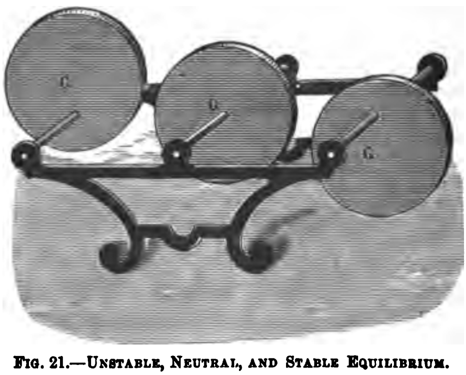


FIG. 21.—UNSTABLE, NEUTRAL, AND STABLE EQUILIBRIUM.

weight on his back, he leans forward, and in carrying it in one hand he leans sidewise, for the same reason.

92. **Stability.**—The position of a body is *stable* when any

overturning force beginning to act will tend to cause its centre of gravity to rise, as a brick lying flat; for then it will of itself return to its original position when the force is withdrawn. It is *unstable* when the slightest overturning force causes its centre of gravity to fall, as a cane balanced on end, in which case it will not recover its position, but will go farther from it. It is *neutral* when the overturning force causes motion in a horizontal line, as a ball on a floor; then it will come to rest in any position.

93. **Measure of Stability.**—The more the centre of gravity has to rise in overturning, the more stable the body is. A brick on its flat side is more stable than a brick on end. To overturn it the centre of gravity has to be raised through the vertical height *ab*, which is a much greater distance in one case than in the other, and therefore a much greater force is required. The work done in overturning is the weight multiplied by *ab*.

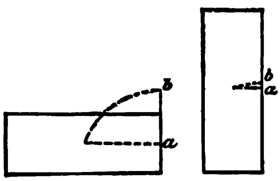


FIG. 22.—STABILITY.

Exercises.—1. When will a body slide, and when roll, down an inclined plane?

2. In rising from a chair, why do we lean the body forward?

3. Why is it easier to walk on a fence with a long stick in the hand?

4. When is a pendulum in stable equilibrium?

5. A cone balanced on its apex is in what kind of equilibrium? on its base? on its side?

6. Why cannot a person pick up an object from the floor in front of him when standing with his heels against a vertical wall?

7. Should the centre of gravity of a ship be high or low? of a wagon?

8. Why is it easier to suspend an iron ring on a nail on the inside than to balance it on the outside?

9. What would a 200-pound man weigh if moved to within 1000 miles of the centre of the earth? *Ans.* 50 pounds.

FALLING BODIES.

94. **How much a Body will Fall in a Second.**—The attraction of the earth is such that it will cause a body starting from rest to fall about 16.1 feet (about 4.9 metres) in one second. Its velocity at the beginning was nothing, and it increased uniformly during the second. Hence at the end it is moving at the rate of 32.2 feet (9.8 metres); that is, it has acquired a velocity which if continued uniformly would carry it over 32.2 feet (9.8 metres) the second second. But during this second second it has also the pull of the earth, adding 16.1 feet more to the space passed over, making 48.3 feet, or three times 16.1 feet, in that second. The third second it has an acquired velocity of 64.4 feet, and an additional pull of 16.1 feet, making 80.5 feet, or five times 16.1 feet, as the fall during the third second.

In general, the fall through any second is found by taking the series of odd numbers, 1, 3, 5, 7, etc., and multiplying 16.1 by the number in the series corresponding to the given second.

Let it be required to find the fall during the sixth second. The sixth number of the series is 11.

$$11 \times 16.1 = 177.1 \text{ feet.}$$

The space fallen through in the first three seconds will evidently be $(1 + 3 + 5) \times 16.1$; in the first five, $(1 + 3 + 5 + 7 + 9) \times 16.1$; and so on.

The sum of the numbers in the parenthesis is found by adding the end terms, and multiplying by half the number of terms, or the number of seconds.[1]

---

[1] If the ninth second is given, we find the odd number corresponding by multiplying 9 by 2 and subtracting 1. If we add the first two odd numbers, it gives the square of 2; if the first three, the square of 3; and so on. Thus, $1 + 3 = 4$, $1 + 3 + 5 = 9$, $1 + 3 + 5 + 7 = 16$. We thus see a reason for the rule, to be announced farther on, that the spaces passed over vary as the squares of the times.

To find the space through which a body would fall in nine seconds, we add the end terms 1 and 17, and multiply by $\frac{9}{2}$ and by 16.1, or

$$(17 + 1) \times \tfrac{9}{2} \times 16.1 = 1304.1 \text{ feet.}$$

95. **Formulæ for Falling Bodies.**—But it is better to work out some general formulæ.

Let s represent the space passed over;
" t " " time;
" v " " velocity;
" g " " acceleration produced by gravity in one second $= 32.2$ feet $= 9.8$ metres, which is taken as the measure of gravity. As g is the velocity acquired in one second, in t seconds we will have

$$v = gt. \tag{1}$$

But as the velocity uniformly increases from nothing to gt, the mean velocity is $\frac{1}{2}gt$, and the space passed over in t seconds with this velocity is

$$s = \tfrac{1}{2}gt \times t = \tfrac{1}{2}gt^2. \tag{2}$$

From (1), $$t = \frac{v}{g}. \tag{3}$$

Substitute in (2),

$$s = \tfrac{1}{2}g \times \frac{v^2}{g^2} = \frac{v^2}{2g}, \text{ or} \tag{4}$$

$$v = \sqrt{2gs}. \tag{5}$$

From (2) $$t = \sqrt{\frac{2s}{g}}. \tag{6}$$

Note.—We said (page 38) that the potential energy which a body has when raised above a plane is equal to the actual energy of its motion when it falls to that plane; in other words, that

$$ws = \tfrac{1}{2}mv^2.$$

We can now prove this. The weight of a body is equal to the number of its particles multiplied by the pull on each, or

$$w = mg.$$

Also, from (4), $s = \frac{v^2}{2g}$.

Multiplying these together, we have $ws = mg \times \frac{v^2}{2g} = \frac{1}{2}mv^2$, which is what we wanted to prove.

These formulæ enable us to work out all possible cases of falling bodies. We seek for one in which the desired quantity constitutes the first member, and in which the last member is all known.

Exercises.—1. How far will a body fall in 8 seconds? We want s, and have given t and g: hence use formula (2).

2. How long will it take a body to fall through 200 metres? Use (6).

3. What velocity would a body acquire in each of the last cases?

4. A body has a velocity of 400 feet per second: through what space and how long has it been falling?

5. A body has a velocity of 40 metres a second: through what space and how long has it been falling?

96. **Projection Upward.**—When a body is projected upward, the attraction of the earth takes away from its energy of motion, and when it falls it gives it back again. It has the same velocity in coming down that it had in going up at the same height. The circumstances of the motion are just reversed.

1. How high will a body rise by an upward impulse of 80 metres per second?

Use formula (4).

$$s = \frac{6400}{19.6} \text{ metres.}$$

2. A bullet is shot up with a velocity of 1600 feet per second: how high will it go?

3. A body rises to the height of 300 metres: how long did it take it?

97. **Resistance of Air.**—All the above is on the supposition that the motion is in a vacuum. The resistance of the air very materially alters the results in real cases. A body will not rise as high as it otherwise would, nor will it fall with nearly the velocity with which it was projected.

98. **Parabola of a Projectile.**—In the case of bodies projected not vertically, were there no resistance the body would move in a symmetrical curve called a *parabola*,[1] and

[1] A parabola is a curve every point of which is equally distant from a point f, Fig. 24, and from a straight line ec. When a gun is

would have equal velocities at equal heights. In practice, it descends more steeply than it rises. The curve is something like that represented in Fig. 23.

FIG. 23.—CURVE OF A BALL.

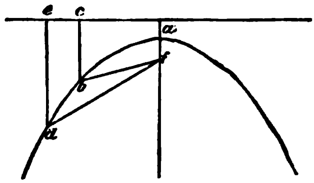


FIG. 24.—PARABOLA.

Experiment 17.—Get one of your friends to knock a ball, and take a side view of the curve.

If a body were projected horizontally from the top of a tower, it would reach the level at the same time as if it were dropped. Moreover, it would reach the level at the same time whatever its velocity of projection. For gravity is the only downward force acting, and a horizontal impulse will not change the circumstances of its motion vertically. It is a general law that a force at right angles to the motion of a body cannot change its velocity, though it may its direction.

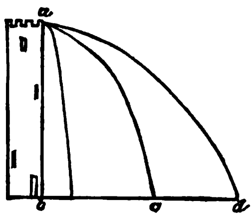


FIG. 25.—PROJECTION HORIZONTALLY.

The *range*, *bd*, of a projectile is equal to the velocity of discharge multiplied by the time it is moving. For the discharge is caused by an impulsive force, which tends to produce uniform velocity. Gravity acting at right angles does not cause any change in this *horizontal* velocity. The projectile moves faster, but it does not get along in a horizontal direction any faster in one part of its flight than in

shot horizontally, the curve, except for the resistance of the air, would be a semi-parabola, *ab*.

another. The same is true if it be projected from the ground at an angle upward.

THE PENDULUM.

99. **What is a Pendulum?**—The pendulum is a body suspended by a flexible cord, so that it may freely vibrate. When drawn aside from a vertical line, the weight is raised and gravity causes it to descend. Its inertia will then carry it up the other side, and were it not for friction and the resistance of the air it would rise to the height from which it fell, and swing back and forth forever. On account of these resistances it does not rise so high, but makes shorter and shorter vibrations, and is finally brought to rest.

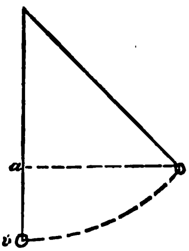


FIG. 26.—PENDULUM.

100. **Energy of a Pendulum.**—When drawn aside, it has energy of position equal to its weight multiplied by *ab*; this is converted into energy of motion in the fall, and this is reconverted to energy of position in the ascent, except such portion of it as appears as heat in point of suspension and in the air. Finally the whole energy is converted into heat, and the pendulum remains at rest.

101. **Simple Pendulum.**—The laws of pendulums are investigated mathematically by considering an ideal pendulum of which the bob is a single point without size, yet with weight, and the string perfectly inelastic and without breadth, the whole moving without any resistance. This arrangement is called a *simple pendulum.* The real pendulum, the *compound pendulum*, approaches in its motions to this. The longer and finer the string, the more nearly do its motions conform to those of the simple pendulum.

102. **Equation of Pendulum.**—The following equation has been found to give the circumstances of the motion of a simple pendulum:

$$T=\pi\sqrt{\frac{l}{g}},$$

in which

$T=$ time of complete vibration;
$l=$ length of pendulum;
$g=$ force of gravity;
$\pi=3.1416=$ ratio of circumference to diameter of a circle.

From this equation[1] we have the following laws:

103. **Laws of the Pendulum.**—1. *The times of all pendulums of the same length at the same place are independent of the extent of the vibration.* A long swing will be performed in nearly the same time as a short one.

This is only approximately true in the case of the ordinary pendulum; a pendulum can be so arranged that it will be strictly true.

2. *The times of different pendulums at the same place are proportional to the square roots of their lengths.* The time of vibration of a pendulum four times as long as another is twice as great.

3. *The times of pendulums of the same length are inversely proportional to the square root of the intensity of gravity.*

To find the intensity of gravity at any place, we should measure the length of a pendulum, count the time of its vibration, and then in the formula $T=\pi\sqrt{\frac{l}{g}}$ we have all the terms but g, which may be readily found. This supposes that we have a simple pendulum. If we have a compound pendulum, we must exhaust the air around it, diminish the friction at its point of support, increase the flexibility of the cord as much as possible, and make certain allowance for the size of the bob.

These laws are independent of the nature of the material of the bob.

Experiment 18.—Procure pendulums made of some heavy material, as lead, suspended by long silk cords to the ceiling.

[1] The equation is proved by Higher Mathematics.

1. Take two of them of the same length, draw one aside farther than the other, and let them go at the same instant. Notice the equality of their times. Or take a long pendulum and count its vibrations in a minute when the vibrations are long and when they are short.

2. Make one just four times as long as the other; notice that the short one swings twice while the long one swings once.

3. Change the length till you have it vibrating once in a second; measure this length, and compare it with that obtained from the formula by making $T = 1$, $g = 32.2$, and $\pi = 3.1416$.

A pendulum which vibrates once in a second is called a *seconds pendulum*.

104. **Pendulum for Clocks.**—The utility of a pendulum for clocks may be explained by Fig. 27. The pendulum swings between two arms a, and is connected with the rod o and the *escapement mn*. The *pallets* of this work into the teeth of the *escapement-wheel R*. When the pendulum swings, one of the teeth of the wheel escapes from the pallet m, and the weight, which acts on R, falls a little, and moves the train of machinery. But directly the pallet n catches and holds it again. So the pendulum simply regulates the motion of the machinery. Swift vibrations make the clock go faster, and slow vibrations make it go slower. As a long pendulum swings slower than a short one, by lengthening the pendulum the rate of the clock is diminished, and *vice versa*. As heat produces this result in a metal bar, it is necessary to compensate for this. This may be done by a gridiron pendulum so arranged that when some of the bars expand downward and lengthen the pendulum, the others expand upward and shorten it. By making these of different materials the expansion in one direction may be made just to balance that in the other.

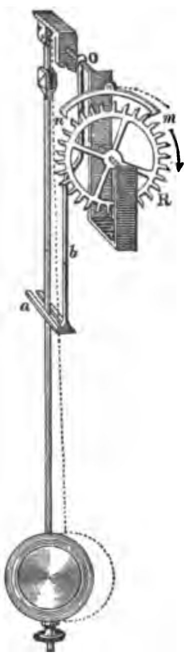


FIG. 27.—PENDULUM FOR CLOCKS.

MACHINES.

105. **The Mechanical Powers.**—All machines, however complex, are combinations of one or more of the six *mechanical powers*,—viz., the *lever*, *wheel and axle*, *pulley*, *inclined plane*, *wedge*, and *screw*.

THE LEVER.

106. **The Lever.**—The lever is a bar which can be turned about a support. This support is called the *fulcrum*. The *power* and the *weight* act on this bar at different points. The relative positions of fulcrum, power, and weight determine the kind of the lever.

FIG. 28.—LEVER OF THE FIRST KIND.

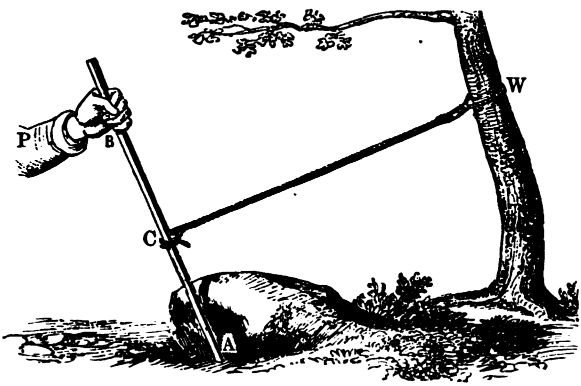


FIG. 29.—LEVER OF THE SECOND KIND.

107. **Kinds of Lever.**—A lever of the first kind has the

fulcrum between the power and the weight, as in a steel-yard or a crow-bar.

A lever of the second kind has the weight between the power and the fulcrum, as in a nut-cracker or an oar, or in a crow-bar used as in Fig. 29.

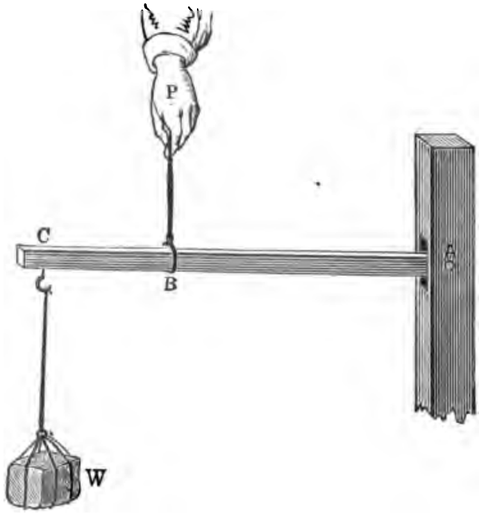


FIG. 30.—LEVER OF THE THIRD KIND.

A lever of the third kind has the power between the weight and the fulcrum, as in the treadle of a lathe.

Questions.—What kind of lever is a balance? a see-saw? a pair of scissors? a ladder raised by a man near its base? the forearm of a man? a pair of tongs? pincers? a wheelbarrow? sheep-shears? the handle of a water-pump? a claw-hammer used in drawing a nail? the rudder of a ship?

Where is the fulcrum in each case?

108. **Law of the Lever.**—The law of the lever in equilibrium is that the moment of the power is equal to the moment of the weight; that is (Figs. 28, 29, 30),

$$p \times ab = w \times ac.$$

In this equation, if we know any three terms, the remaining one can be found.

Exercises.—1. Given $p = 20$, $ab = 8$, $ac = 6$. Find w.
2. Given $p = 18$, $ab = 8$, $w = 240$. Find ac.
3. Given $p = 5$, $w = 200$, $ab = 400$. Find ac.
4. Given $ab = 40$, $ac = 80$, $w = 200$. Find p.
5. Given $ac = 20$, $p = 2$, $w = 50$. Find length of lever.

Experiment 19.—Take a rod and mark it off in inches. Place a fulcrum near one end, and a 5-pound weight 2 inches from the fulcrum. Balance it with a 1-pound weight. It will have to be just 10 inches from the fulcrum. Vary the weights and the distances.

109. **Ratio of Power and Weight.**—Whenever the lever-arm of the power is greater than the lever-arm of the weight, the power is less than the weight. In levers of the first kind the power may be greater or less than the weight; in the second kind it is always less; and in the third kind it is always greater.

110. **Spaces vary inversely as Forces.**—The space through which the power and weight act is always proportioned to their lever-arms, and hence in inverse ratio to their magnitudes. In order to lift w to w', p has to move to p', a distance just as many times greater than ww' as w is greater than p, or as ap is greater than aw. We gain power, but we have to move through a greater space and with greater velocity. It is a general law in machinery that the distances through which the power and the weight move are inversely proportional to their magnitudes, and since by "work done" we mean the force multiplied by the distance through which it moves, we have another law for the lever,—the *work done by the power is equal to the work done by the weight.*

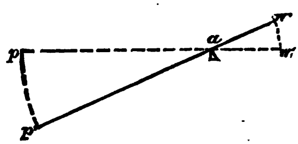


Fig. 31.—The Lever.

111. **The Balance.**—The balance is a lever of the first kind. Its accuracy will depend on the exact equality of the two arms, and may be tested by first weighing a substance, then reversing weights and substance. If they still balance, it is correct. By its sensitiveness we mean the

amount of weight which, placed in either pan, after being exactly balanced, will cause it to turn. The smaller this weight, the more sensitive it is. The sensitiveness is increased by diminishing friction at the points of turning, by placing the centre of gravity of the beam near the point of support, and by making the beam long and light. The first is accomplished by making the fulcrum of a piece of steel called a knife-edge.

FIG. 32.—THE BALANCE.

112. Bent Levers.—If the lever is bent, and the forces are not parallel, the general law still holds. But we must measure the lever-

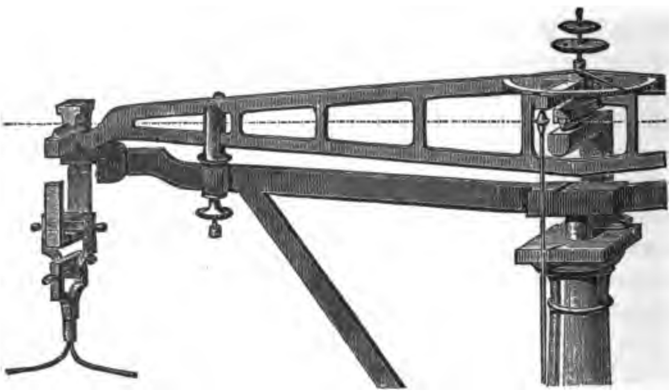


FIG. 33.—ARM OF A DELICATE BALANCE.

arms from the fulcrum perpendicular to the direction of the force. In the figure (34) the arms are *ab* and *ac*.

113. Compound Levers.—If one lever acts on a second, as in Fig. 35, the power of the second lever is the weight of the first. If

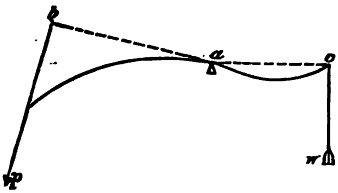


FIG. 34.—BENT LEVER.

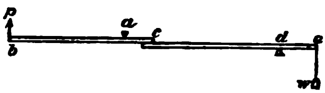


FIG. 35.—COMPOUND LEVER.

$ab = 6$, $ac = 2$, $cd = 5$, $de = 1$, and a power of 10 is applied at b. Then in the first lever,

$$6 \times 10 = 2 \times \text{weight at } c.$$
$$\text{Weight at } c = 30.$$

And in the second lever,

$$30 \times 5 = 1 \times w.$$
$$w = 150.$$

This is also obtained by multiplying the power by the product of the lever-arms of the powers and dividing by the product of the lever-arms of the weights, or

$$10 \times 6 \times 5 \div 2 \times 1 = 150.$$

THE WHEEL AND AXLE.

114. The Wheel and Axle.—The principle of the wheel and axle is the same as that of the lever.

The radius of the wheel ab is the lever-arm of the power, and the radius of the axle ac is the lever-arm of the weight. There is equilibrium when

$$p \times ab = w \times ac.$$

Having given any three of these, the fourth can be found as in the case of the lever.

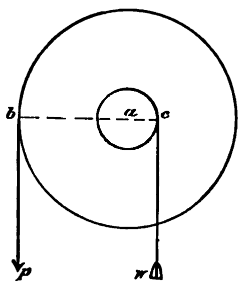


FIG. 36.—WHEEL AND AXLE.

The power is applied by means of a handle, or of a cord wrapped around the wheel, and the

weight is attached by a cord around the axle. The power may act at any angle with the line of the weight, as p', so that the wheel and axle is used for the transmission of force

FIG. 37.—WINDLASS.

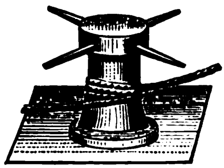


FIG. 38.—CAPSTAN.

in different directions. If they are of the same diameter, there is nothing gained except the change of direction.

The windlass (Fig. 37) and capstan (Fig. 38) are examples of the wheel and axle.

115. **Cog-Wheels.**—If the wheel or the axle has teeth which work into similar teeth in other wheels, we will have a train of cog-wheels. The law of equilibrium of such a train is: the weight multiplied by the product of all the radii of the axles is equal to the power multiplied by the product of all the radii of the wheels.

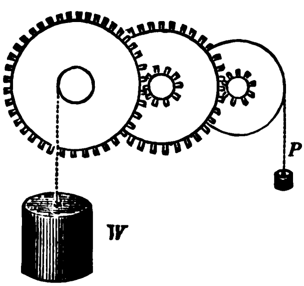


FIG. 39.—TRAIN OF WHEELS.

Since the teeth of a small wheel are the same distance from one another as the teeth of a larger wheel in which it works, when it makes a complete revolution the larger one has only turned part way round. If one has half as many teeth as the other, it will make two revolutions to one of the other. It will, therefore, travel twice as fast. But the number of teeth is proportional to the circumferences, and hence to the radii, of the wheels. Hence we have the prin-

ciple that the velocity of connected wheels is inversely proportional to their radii.

116. **Train of Wheels.**—An axle with cogs is called a *pinion*. If a power turns a wheel the pinion of which works in another wheel, the pinion of this in another wheel, and so on, we have great increase of power, but we lose velocity. If we apply our power to the other end of the train, the last wheel, we gain great velocity when we reach the first pinion, but we lose power in the same proportion. The first method is used when we want a small power to move a heavy weight, and the latter when we want to gain a great velocity.

Wheels may also be connected by means of belts. The circumstances of motion are the same as in a train of cog-wheels. In this case the friction between the belt and the surface of the wheel takes the place of the cogs, and the advantage is that power can be communicated through a long distance.

Exercises.—In the following examples let R stand for the radius of the wheel and r for the radius of the axle.

1. Given $R = 20$, $r = 5$, and $P = 200$, to find W.
2. Given $R = 20$, $P = 100$, and $W = 1000$, to find r.
3. Given $R = 20$, $r = \frac{1}{2}$, and $W = 500$, to find P.
4. Given $r = \frac{1}{2}$, $W = 1000$, and $P = 40$, to find R.
5. In lifting an anchor which weighs 1000 pounds, four men work a capstan having a radius of 2 feet, by bars the outer ends of which are 6 feet from the centre of the barrel. How much force does each exert? *Ans.* 83.3+ pounds.
6. A power of 5 pounds acts on a wheel with a radius of 1 foot. The pinion (2 inches radius) acts in a wheel of 1 foot radius. This is repeated 3 times. What weight may be lifted? *Ans.* 1080 pounds

THE PULLEY.

117. **Fixed Pulley.**—The pulley consists of a wheel working in a block. In its simplest form it is used to change the direction of a force. In this case there is no power gained; a little is lost by friction and by the rigidity of the rope; but, except these, it is carried over without loss or gain. In the figure the downward force becomes an upward one, and can be applied to lifting weights. Such a pulley is called a *fixed pulley*.

118. **Movable Pulley.**—The case is different when we have a pulley such as is shown in Fig. 41. Here the weight is supported by both branches of the cord above

the pulley, hence the tension on each need be but half

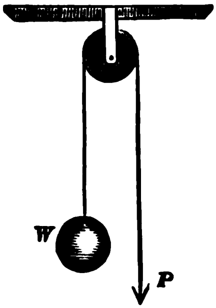


FIG. 40.—FIXED PULLEY.

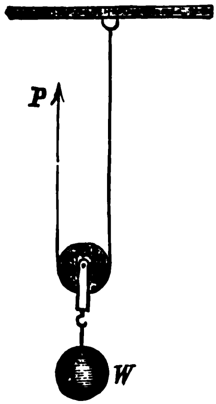


FIG. 41.—MOVABLE PULLEY.

the weight; that is, for equilibrium, *W* must be twice *P*. A pulley of this kind will, therefore, enable a power of one pound to lift a weight of two pounds. Such a pulley is called a *movable pulley*.

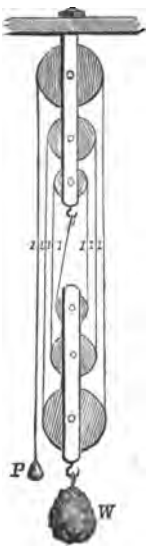


FIG. 42.—COMBINATION OF PULLEYS.

119. **Work done.**—Since, when *W* is lifted any distance, the pulley is elevated the same amount, the ropes at both *a* and *b* will be shortened, and *P* will have to rise through twice this distance. Hence, as in the lever, in order to gain the advantage of the movable pulley, we lose space and time. The work done by the power is equal to the work done by the weight.

120. **Combination of Pulleys.**—In the combination of pulleys of Fig. 42, the three upper ones are fixed pulleys, and only change direction. The three lower are movable pulleys, and each doubles the effective force applied to it, so that a power can lift a weight six times its own weight. The general rule for pulleys is that a power

can lift a weight as many times greater than itself as twice the number of movable pulleys.

How would this rule be affected if the rope began at the upper movable pulley?

Exercises.—1. In Fig. 43, how much weight will a power of 20 pounds lift?

2. If the power moves through 30 feet, how far will the weight move?

3. How much power will be required to lift a weight of 1 kilogram through 1 metre, and through what distance will it move?

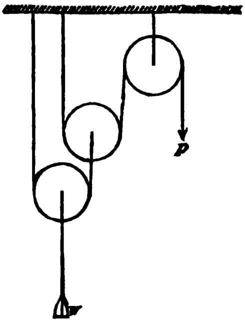


FIG. 43.—PULLEYS.

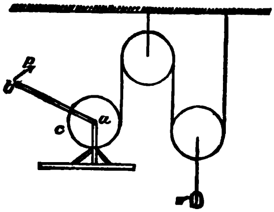


FIG. 44.—PULLEY AND WINDLASS.

4. In a system of pulleys, a power of 2 pounds balances a weight of 24 pounds: how many movable pulleys are employed?

5. In the combination of pulley and windlass of Fig. 44, *ab* is 2 feet, *ac* 6 inches. A power of 30 pounds is applied at *b*: how much weight can be lifted?

6. How many turns will be required to lift the weight through 3 feet?

THE INCLINED PLANE.

121. **Law of the Inclined Plane.**—Less power is required to roll a body up an inclined plane than to lift it through the height of the plane. Hence we gain by its use.

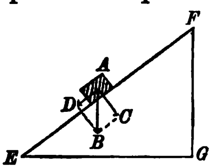


FIG. 45.—INCLINED PLANE.

Let A be a body resting on an inclined plane, EF. Let the weight of the body be represented by the line AB, directly downward. Let this be resolved into two forces, AC, perpendicular to the plane, and AD, parallel

to it. Then AC makes pressure against the plane, and AD tends to make the body roll or slide down; and if a force parallel to EF, and equal and opposite to AD, be applied to the body, it will be in equilibrium.

By geometry we readily prove the proportion that

$$AD : AB :: FG : EF,$$

or, as the force required to hold the body on the plane, which we may call the power, is to the weight of the body, so is the height of the plane to its length. When the power acts parallel to the plane, we have then for equilibrium,

Power : Weight :: Height of Plane : Length,

or, the weight is as many times greater than the power as the length is greater than the height of the plane.

Exercises.—In the above case,—1. Given $EF = 10$, $FG = 5$, $W = 200$. Find P.

2. Given $EF = 10$, $FG = 5$, $P = 40$. Find W.
3. Given $EG = 4$, $FG = 3$, $W = 200$. Find P.

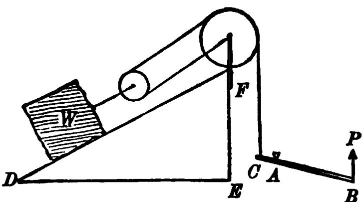


Fig. 46.—Combination of Powers.

4. In the combination of lever, inclined plane, and pulley of Fig. 46, $AB = 10$ feet, $AC = 2$ feet, $DF = 20$ feet, $EF = 8$ feet, $P = 100$ pounds: how large a weight can be lifted?
5. How much power will be needed to lift a ton?
6. How far will P have to move to drag W through 1 foot?

THE WEDGE AND SCREW.

122. **The Wedge.**—If the inclined plane is pushed under the body, it becomes a wedge, and the same rules for equilibrium hold good. The height of the plane is now the back of the wedge, and the weight is as many times greater than the power as the length exceeds the back of the wedge.

Wedges are used for splitting timber, for raising heavy

weights, for cutting and piercing. Knives, scissors, awls, chisels, pins, needles, are wedges.

123. **The Screw.**—A screw is an inclined plane wound around a cylinder.

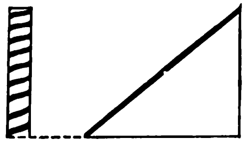


FIG. 47.—SCREW AND INCLINED PLANE.

Experiment 20.—Take a triangle of paper, as in Fig. 47, and wind it around a round piece of wood; it will illustrate how an inclined plane can be made into a screw.[1]

124. **Law of the Screw.**—One complete turn of the screw will lift the weight through the distance which separates the threads. The law of the screw is, therefore, that the weight is as many times greater than the power as the circumference described by the power is greater than the distance between the threads.

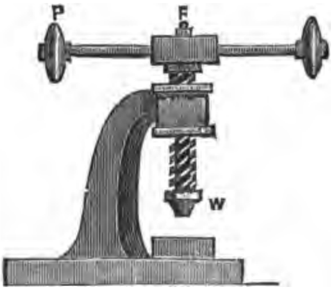


FIG. 48.—THE SCREW.

Exercise.—A power of 30 pounds applied at the end of a lever 2 feet long acts on a screw, the distance between the threads of which is $\frac{1}{20}$ of an inch: how much weight can be lifted?

In the common screw, propelled by a screw-driver, the weight is the resistance of the material penetrated, and the circumference described by the power is the circle through which the largest part of the handle travels.[2]

125. **Friction.**—All the laws of machines are modified by *friction.* Friction is roughness at the point of contact of two surfaces, which prevents them from sliding freely on each other. In levers there is friction at the fulcrum, in the wheel and axle and pulley at the bearings, on the

[1] Such a curve is a helix, and not a spiral, as often stated. A spiral is a curve in one plane.

[2] The distance between the threads of a fine screw is best obtained by measuring an inch along it and counting the number of threads.

inclined plane, wedge, and screw at their surfaces. In all these cases this represents so much resistance, to overcome which additional power is required. It is important to ascertain the amount of friction between surfaces of different kinds, so that its effect may be accurately taken into account in our theories of machines. The following will afford a means of testing its amount.

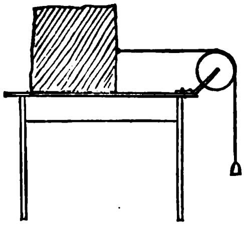


FIG. 49.—DETERMINING FRICTION.

Experiment 21.—Fasten a pulley to the table, as in Fig. 49. Place a block on the table and attach the pulley-cord to it. On the other end of the cord apply weights till the block begins to move. The amount of these weights will measure the friction between the block and the table.

Experiment 22.—Place a brick on end, then on face on the table. The friction will be the same in both cases.

Place a second brick on top of the first, the friction will be doubled.

126. **Laws of Friction.**—By some such arrangement as this it has been found,—

1. That friction is less between metals of different kinds than between metals of the same kind. Hence the advantage of brass bearings for iron axles.

2. That it is proportional to the weight (or pressure), and does not depend on extent of surface in contact.

3. That it is greater at the start than after motion has commenced. A part of the weight may be removed from the cord, and it will continue to descend. The object of lubricants is to diminish friction.

127. **Friction Essential.**—Friction should not be looked upon as a resistance merely: it is indispensable to our welfare. It is the friction between our feet and the ground which saves us from falling at every step. It is the friction between the particles of dirt and the rocks which prevents all the hills from crumbling down and everything being reduced to a dead level. It is the friction of nails and screws which gives them their utility and prevents all our struc-

tures from falling in ruins. It enables the engine to draw us on the track; it gives to belted wheels their value; it enables long ropes to be made out of short strands, and keeps knots tied; it causes the rivers to flow gently along their beds.

128. **Machines do not create Energy.**—We have seen both in the lever and in the pulley that the work done by the power is equal to the work done by or upon the weight or resistance. This is a general law of machines. Whenever we gain power we lose speed, and when we gain speed we lose power. A machine cannot create any energy. It transmits that which is applied to it by an external power. The power does work upon it, and it does work upon the resistance. This work may be of a different kind, but is the same in amount.

129. **Uses of Machines.**—The question then comes up, What do we gain by machines? Sometimes we gain only a change of direction, as in the fixed pulley; sometimes it is an advantage to gain power at the expense of velocity, as in a lever or pulley used to raise a heavy weight; and sometimes it is an advantage to gain velocity at the expense of power, as in the case of a clock, where the slow falling of the weight, or uncoiling of the spring, may cause rapid motion of the hands; or in the sewing- or mowing-machines. Sometimes it is a gain to change the character of the power, as in the steam-engine, where heat produces mechanical motion, or in electric lighting-machines, where heat and motion produce electricity and light. Machines are also a great gain in enabling us to use the power of the wind, of steam, of falling water, and of animals.

130. **Perpetual Motion.**—These examples will show the character of the gains of machinery. In no case is the energy increased by the machine itself. We see, then, the folly of all *perpetual-motion* machines,—machines which will keep themselves running without the addition of any external energy. Any such machine would have to create

energy. Let us suppose that water falling on a wheel would cause such motion of the wheel as would, applied to a pump, force the water up to the level from which it fell. This would be a perpetual-motion machine, for it would keep itself going forever without any new supplies of force. But it requires just as much energy to lift the water up to its level as is given out by the fall. But part of the energy of the fall is required to overcome the friction of the machinery and the resistance of the air, hence there cannot be enough left to raise the water to its old level. If machines could be constructed so as to run without any resistance, perpetual motion would be possible, and under no other circumstances.

Such a machine would be useless for any practical purposes, for if any machinery were connected with it, it would soon bring it to rest, and a new supply of power would be needed.

General Exercises.[1]—1. The minute-hand of a watch is twice as long as the second-hand: show that the end of the second-hand moves thirty times as fast as the end of the minute-hand.

2. Find the space described in the fifth second by a falling body.

3. If a body falls for a quarter of a minute, show that at the end of that time it would be moving at the rate of 483 feet per second, and ascertain what this velocity will be, expressed in miles per hour.

4. A stone dropped into a well is heard to strike the water in two seconds and a half; find the depth of the well. *Ans.* 100 feet.

5. An express train, 66 yards long, moving at the rate of 40 miles an hour, meets a slow train, 110 yards long, moving at the rate of 20 miles an hour; find how long a man in the express train takes to pass the slow train, and how long the express train takes in completely passing the slow train. *Ans.* $\frac{1}{16}$ minute. $\frac{1}{10}$ minute.

6. A river, one mile broad, is running downward at the rate of 4 miles an hour; a steamer can go up the river at the rate of 6 miles per hour; find at what rate it can go down the river. *Ans.* 14.

7. A moving body is observed to increase its velocity by a velocity of 8 feet per second in every second; find how far the body would move from rest in 5 seconds. *Ans.* 100 feet.

[1] In these and other exercises at the ends of the chapters a great variety is given in quality and hardness. The teacher should make a selection adapted to the class. Many classes had better omit all of them, while some would be benefited by working them all.

8. A body is moving at a given instant with a velocity of 40 feet per second; from this instant a constant force is made to act on it in a direction opposite to that of the motion which brings it to rest after it has described 20 feet; find the proportion which this force bears to the weight of the body. *Ans.* About $1\frac{1}{4}$ times.

9. A man jumps suddenly off a platform with a 20-pound weight in his hand: find the pressure of the weight on his hand while he is in the air.

10. Forces represented by 4, 5, and 10 pounds respectively act on a particle: show that they cannot keep it at rest.

11. A, B, C, D is a square. A force of 4 pounds acts from A to B, a force of 6 pounds from B to C, and a force of 10 pounds from C to D: find their resultant. *Ans.* 8.48.

12. It is required to substitute for a given vertical force two others, one horizontal and one inclined at an angle of 45 degrees to the vertical: determine by a diagram the magnitude of these two forces.

13. A weight of 24 pounds is suspended by two strings, one of which is horizontal, and the other is inclined at an angle of 45 degrees to the vertical direction: find by a diagram the tension of each string.

14. A straight rod is bent at right angles, so that one part is twice as long as the other: show how the centre of gravity of the bent rod can be determined.

15. Show that a cylinder, if placed on its flat end, will be in stable equilibrium, but, if placed on its curved surface, in neutral equilibrium.

16. A triangular board is hung by a string attached to one corner: find what point in the opposite side will be in a line with the string.

17. Find where the fulcrum must be placed that 2 pounds and 8 pounds may balance at the extremities of a lever 5 feet long.

18. The arms of a lever are respectively 15 and 16 inches: find what weight at the end of the short arm will balance 30 pounds at the end of the long arm, and what weight at the end of the long arm will balance 30 pounds at the end of the short arm.

19. A straight lever, 6 feet long, and heavier towards one end than the other, is found to balance on a fulcrum 2 feet from the heavier end, but when placed on a fulcrum at the middle it requires a weight of 3 pounds hung at the lighter end to keep it horizontal: find the weight of the lever. *Ans.* 9 lbs.

20. Two men, A and B, carry a weight of 200 pounds on a pole between them; the men are 5 feet apart, and the weight is at a distance of 2 feet from A: find the weight which each man has to bear.

21. Suppose that a body which really weighs 1 pound appears in a balance to weigh 1 pound 1 ounce: find the proportion of the length of the arms.

22. A substance is weighed from both arms of a false balance, and its apparent weights are 9 and 4 pounds: find the true weight.

23. The radius of the axle of a capstan is 1 foot: if four men push each with a force of 100 pounds on spokes 5 feet long, show that on the whole a tension of 2000 pounds can be produced on the rope which passes around the axle.

24. A wheel and axle is used to raise a bucket from a well; the

circumference of the wheel is 60 inches, and while the wheel makes three revolutions the bucket, which weighs 30 pounds, rises one foot: find the smallest force which can turn the wheel.

25. Suppose the power to act parallel to the plane, and that the height of the plane is to its base as 5 is to 12: if the weight is 65 pounds, find the power.

26. Find the relation between the power and the weight in a screw which has 10 threads to an inch, and is moved by a power acting at right angles to an arm at the distance of 1 foot from the centre.

27. A pendulum vibrates 65 times in a minute: how much must it be lengthened to vibrate once in a second?

Solution.— Time of one vibration $= \frac{12}{13}$ second.

Hence, from formula $\frac{12}{13} = 3.1416 \sqrt{\frac{l}{32.2}}$,

$\left(\frac{12}{13 \times 3.1416}\right)^2 = \frac{l}{32.2}$. From this we find l.

In a seconds pendulum we have $1 = 3.1416 \sqrt{\frac{l}{32.2}}$. The difference between the two values of l will be the answer.

28. In what time would a seconds pendulum vibrate at a height of 4000 miles above the earth's surface? at a depth of 2000 miles under ground?

29. How long is a pendulum which vibrates 40 times a minute?

30. A seconds pendulum, carried up a mountain, vibrates 58 times a minute: what is the force of gravity?

CHAPTER III.

LIQUIDS.

SECTION I.—HYDROSTATICS.

131. **Definitions.**—In Art. 25 we were taught that liquids are substances in which there is perfect freedom of the molecules among themselves, and that they change their form with the slightest force. No liquid fulfils these conditions perfectly, but many do this near enough for all practical purposes. Water is commonly used as the typical liquid, and will be so used here.

Liquids will be treated under two heads,—liquids at rest and liquids in motion. *Hydrostatics is the science which treats of liquids at rest.*

132. **Liquids almost Incompressible.**—Liquids can scarcely be compressed even if subjected to the greatest pressure. Indeed, it was formerly thought that they could not be compressed at all. Many years ago some philosophers in Florence filled a hollow silver ball with water, and, after closing the opening, squeezed the sides together by great pressure. This pressed the ball out of its spherical shape, and, as this would make the cavity smaller,[1] they hoped to

[1] It is proved in higher mathematics that a hollow sphere has a greater capacity than a vessel of any other shape which is enclosed by the *same surface*. Hence, when the shape of the silver vessel was changed, its shell would not hold so much water; but, as indicated above, instead of shrinking to fit its smaller quarters, the water oozed through the sides.

Tyndall calls attention to the fact that Bacon performed this experiment fifty years before it was performed in Florence; but this fact is generally unknown, and Bacon seldom gets credit for it.

compress the water. But, instead of shrinking in bulk, the water came through the thick silver sides, *and spread over the outside like dew.*

But by using better apparatus modern experimenters have been able to compress water and other liquids slightly. To compress a quantity of water whose upper surface is a foot square into a bulk only $\frac{1}{100}$ less would require a pile of iron weights, each 1 foot square, *more than* $\frac{1}{6}$ *of a mile high.* For all practical purposes, therefore, water is incompressible. This property of liquids will be illustrated presently in water machinery, and is of great use to us there.

133. **Liquids perfectly Elastic.**—If liquids are compressed, and even if kept compressed for a great length of time, they always expand to their original bulk when the pressure is removed. Hence we infer that they are perfectly elastic.

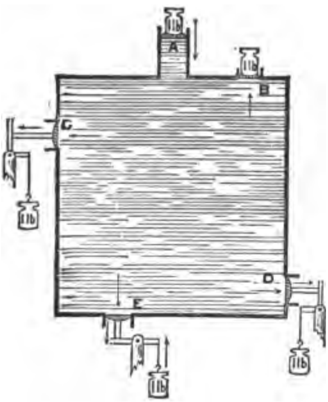


Fig. 50.—The Pressure of Liquids the same in every Direction.

Experiment 23.—Throw a flat stone very slantingly on the surface of a pond of still water, and notice how it rebounds or "skips" again and again. What causes it? Does a stone skip so well on smooth ice? Why not?

134. **Liquids transmit Pressure equally in all Directions.**—The most remarkable and important fact about liquids is that whenever any pressure is put upon one, *the liquid presses out with the same force in every direction.*

In Fig. 50, the piston A presses down upon one square inch of water with a force of 1 pound. This force is transmitted to every part of the surface, and the liquid therefore presses with the force of 1 pound upon each square inch of the surface of the vessel, as is shown by its sustaining the weights at B, C, D, and E.

To which class does the lever at C belong? at D? at E? Has

the weight of the water been taken into account here? Would it make any difference?

135. **The transmitted Pressure proportional to the Surface.**—In Fig. 51, if the small tube is 1 inch square and the large one 4, then the area of the water pressing on the large piston is 16 times[1] as great as upon the small one, and with an upward pressure of 1 pound upon each square inch of B, the whole upward pressure then is 16 pounds. This is called the hydrostatic paradox, because it seems paradoxical (or beyond belief) that 1 pound should balance 16 pounds.

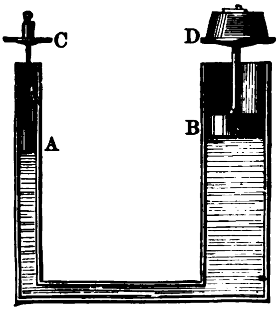


FIG. 51.—THE HYDROSTATIC PARADOX.

136. **The Hydrostatic Press.**—If more than a pound be placed upon C (Fig. 51), the piston A will be forced down and D will be raised. In this way a small weight can be made to raise a very large one. This is the principle of the hydrostatic press, which is shown in Fig. 52. In order that all of the parts, and the manner of working, may be seen, the figure represents the press cut open through the middle, or *in section*, as this is called. The raising of the piston *p* sucks up water from *m*. When the handle HE is pushed down again, a valve keeps the water from going back into *m*, and it is forced through the narrow tube into M, and the large piston P is raised and pressed against the cotton-bale C with great force. If *p* is 1 inch in diameter, and P 10 inches, for every pound down upon *p* there is a pressure of 100 pounds upon the cotton-bale. This force is usually further increased by using a lever, GE (which class?), to increase the pressure upon *p*.

[1] The student will not forget that the *areas* of similar surfaces vary according to the *squares* of their like dimensions.

137. The Hydrostatic Press creates no New Force.—The hydrostatic press may seem to contradict Art. 130, where it is said that power is never created by machinery. But

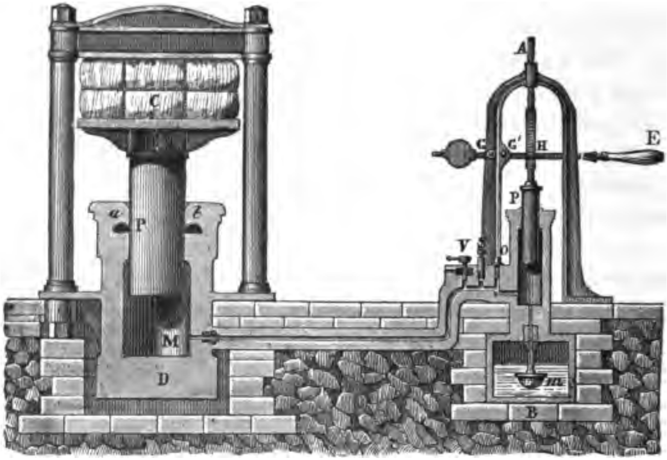


FIG. 52.—THE HYDROSTATIC PRESS.

the surface of the water which presses up against P is 100 times as great as that pressed upon by p, and therefore when the small piston has been forced down 1 foot P has been raised only $\frac{1}{100}$ of a foot. So that our force of 1 pound moving through 1 foot has been changed to a force 100 times as great, but moving through only $\frac{1}{100}$ of a foot, and therefore exactly equivalent to the first force.

The loss of power by friction has not been taken into account here, and less power is lost by it in this machine than in almost any other.[1] On this account, and because

[1] About 10 per cent. of the power is usually lost by friction. The principle of the hydrostatic press has been known for more than two hundred years, but no way of making the joints tight enough to resist the enormous pressure of the water was found until Bramah, an English inventor, about the beginning of the present century, invented a curved leather collar for this purpose, shown in Fig. 52, at *a* and *b*.

by enlarging P almost any power can be accumulated there, this machine is in common use where great force is needed.

138. **Pressure on the Bottom of a Vessel.**—In a vessel whose bottom is level and sides perpendicular, the pressure of the water upon the bottom is evidently equal to its weight, as in Fig. 53, A. If, now, a vessel with a narrow stem, but widening into a broad base, as in Fig. 53, B, be filled with water, the water at *a*, being pressed upon by the weight of the column of water above it, transmits this pressure equally in *every* direction to the water surrounding it. This does the same in turn, so that the pressure on every part of the bottom of the vessel is the same as on the part under the column. Then, in Fig. 53 C, the pressure at E is equal to that at D, and therefore the pressure at F (or at H), is the same as it would be at *f* if the first joint of the pipe were extended straight down to *f*. And also the pressure at M or O is the same as it would be at

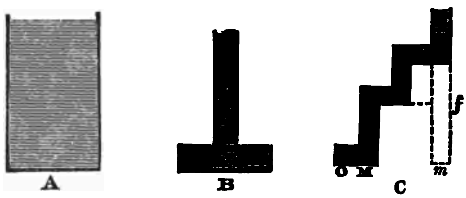


FIG. 53.—PRESSURE VARIES WITH THE DEPTH.

m. If the tubes were curved, or had any other shape, the pressure on the bottom would be the same. Hence the following important principle: *In a vessel of any shape whatever, the pressure of a liquid upon the bottom is the same as if the sides rose perpendicularly around the bottom, and it were filled with the liquid to the same height as at present.*[1]

The space underneath this collar is connected with M, so that the water presses the collar tighter above the piston as the pressure in M grows greater, and prevents the water from leaking there. From this discovery the hydrostatic press is sometimes called Bramah's press.

[1] The bottom of the vessel is understood to be horizontal,—that is,

A cubic foot of water weighs 1000 ounces, or 62½ pounds.[1] Therefore, to find the pressure of water on the bottom of a vessel, find the number of cubic feet in a column of water whose base is the bottom[2] of the vessel and whose height is the *perpendicular* height of the surface of the water above the base, and multiply 62½ pounds by this number.

139. **Pascal's Experiment with the Vases.**—The apparatus

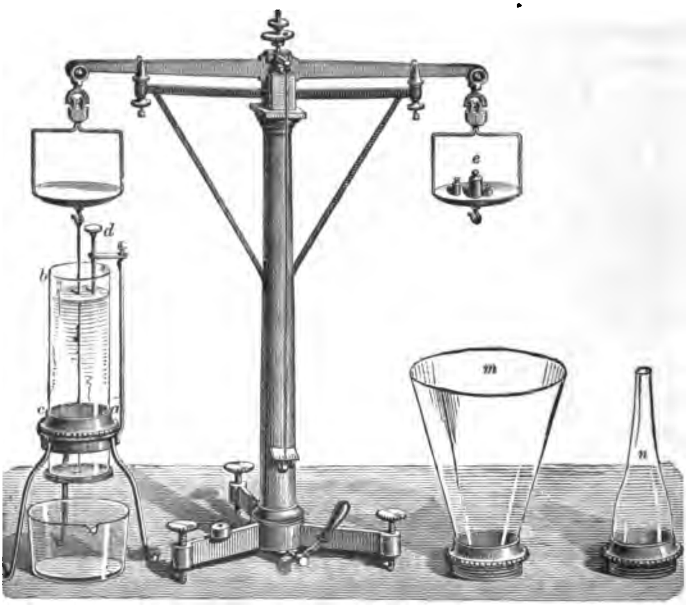


FIG. 54.—PASCAL'S VASES.

shown in Fig. 54 was devised by Pascal[3] to prove these truths ex-

---

level. For the pressure upon the bottom when it is not horizontal, see Art. 140.

[1] More exactly, a cubic foot of *pure*, *fresh* water at 32° F. (what does that mean?) weighs $62\frac{417}{1000}$ pounds, and slightly less at higher temperatures. A cubic foot of sea-water weighs about $64\frac{1}{3}$ pounds.

[2] Should the outside or the inside area of the bottom be taken?

[3] Pascal (Pas′kal) was born in France in 1623, and died there in

perimentally. The bottom of the glass tube *ca* is loose, and hangs by a string from one arm of a balance. Small weights are put on the other arm until they balance the bottom and the string. The glass tube *bc*, whose sides are perpendicular, is screwed on at *c*, an additional weight of 1 pound is put into the scale-pan *e*, and water is poured into *bc*. The pound-weight holds the bottom close against the end of the tube until a *pound* of water has been poured in. Then the water pushes the bottom down, and runs out as fast as more is poured in, the marker *d* having been set so as to show the height of the water when it began to run out.

If, now, *bc* be unscrewed and *m* be screwed on in its place, it will be found that water must be poured in to exactly the same height as at first before it will loosen the bottom and run out, although, because of the widening out of *m*, there may be 2 pounds of water in it then, thus proving that *the pressure on the bottom depends only upon the area of the bottom and the perpendicular height of the water.* If *n* be used, perhaps half a pound of water will fill it up to the marker *d* and start the flow of water.

140. **Pressure on the Sides of a Vessel.**—Since the pressure is transmitted equally in all directions, at the edge of the bottom of a vessel the pressure of the liquid on the side is the same as on the bottom. Half-way up to the surface it is the same as the downward pressure at that depth, or half as great as at the bottom. At the surface there is no pressure on the side. Therefore the *average* pressure per square inch on the side is half as great as on the bottom. If, then, a cubical vessel be full of water, the pressure upon each of the four sides is one-half that upon the base.

In the above case the sides of the vessel are supposed to be rectangles, perpendicular to a horizontal base. In general, the average pressure upon the perpendicular sides of *any* shape is the pressure upon the centre of gravity of the part of that side under water.

If the side of a vessel is not perpendicular, the pressure upon the part of the side under water is the same as if that part were laid level and covered with water to the *average* depth of the water upon the inclined side, or to the depth of the centre of gravity of the side.

1662. He was a very brilliant scientist, who did much for Natural Philosophy, especially in the subject we are now considering. He wrote a book on Conic Sections when in his sixteenth year.

A vessel's *base*, which is not horizontal, may be considered as an inclined side, and the pressure upon it found in the same way. This is a different thing from the *downward* pressure in such a vessel. That is the same as the *weight* of the water, and would be found by taking a *horizontal section through the water* and its average depth.

141. **Pressure on the Top of a Vessel.**—There may also be an upward pressure upon the top of a vessel. Thus, in a vessel shaped as in Fig. 55, the pressure upward at H or F is just the same as the pressure downward at B.

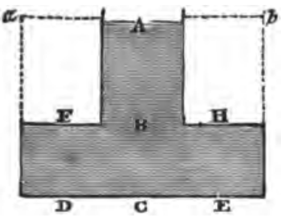


FIG. 55.—UPWARD PRESSURE OF LIQUIDS.

Students sometimes cannot see how the pressure upon the bottom DCE can be as great as if the sides went up to *a* and *b*, and yet when put upon scales and weighed the whole will not weigh nearly so much as the other vessel of water would. It is because the pressure upward at F and H counterbalances a part of the pressure downward at D and E. A foot-ball might be blown so full that the air would press outward against the cover with a force of several pounds to the square inch, and yet ordinary scales would not show it to be any heavier than when empty. The pressure within is as great up as down, and so does not add to the weight.

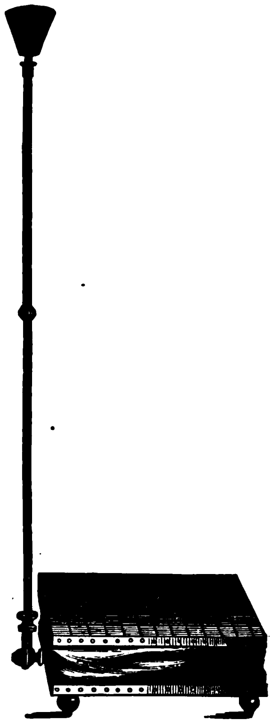


FIG. 56.—THE HYDROSTATIC BELLOWS.

142. **The Hydrostatic Bellows.**—Fig. 56 shows a common piece of apparatus which well illustrates these principles.

The narrow tube, about six feet long, is screwed into the bellows, and water poured into the tube will raise a heavy weight on the bellows. When the bellows are distended, an additional pound of water may easily sustain 100 pounds more on the bellows.

Few persons appreciate the amount of pressure caused by a considerable depth of water. Pascal long ago showed that a strong cask could be burst by screwing into it a long tube and filling cask and tube with water. Tanks and cisterns would be much less likely to leak if made wide and shallow, than if made narrow and deep. The pressure in the water-pipes of cities and towns is often very great.

Exercises.—1. Why are canal-banks and dam-breasts made thicker below than above?

2. If water be thrown hard against a wall, will it trickle down the wall, or fly off? Why?

3. If in the vessel shown in Fig. 51 one side of A is 2 inches and one side of B 12 inches, and if 5 pounds were put upon C, what weight upon D would it balance? *Ans.* 180 pounds.

4. What weight must be put upon C to balance 396 pounds upon D?

5. If *you* should stand upon C, what weight upon D would you balance?

6. If you should stand upon D, what weight upon C would balance you?

7. What weight must be put upon C to make B stand 1 foot higher than A? *Ans.* $1\frac{53}{72}$ pounds.

8. What, if B were 6 inches square? *Ans.* $1\frac{53}{72}$ pounds.

9. What, if B were 1 foot square and A 6 inches square? *Ans.* $15\frac{5}{8}$ pounds.

10. In a hydrostatic press the diameter of the small piston is 1 inch and that of the large piston 12 inches: how great a weight will be raised by a downward pressure of 50 pounds upon the small piston? *Ans.* 7200 pounds.

11. If GE (Fig. 52) is 3 feet and GH 6 inches, what weight will be balanced by 50 pounds at the end of the handle? *Ans.* 43,200 pounds.

12. If friction were taken into account, how much would these be reduced to?

13. If a tight cover were put upon B (Fig. 53), and it were turned upside down, would the pressure of the water upon the new base be the same as upon the old one?

14. Would the pressure per square inch be the same?

15. Would it weigh the same in a pair of scales?

16. There are 2150.4 cubic inches in a bushel: what weight of water would fill a peck measure? *Ans.* $19\frac{4}{9}$ pounds.

17. If the room in which you recite these lessons were filled with water, what would it weigh?

18. A *cubical* vessel is full of water: how many times its weight is the pressure of the water upon the sides and bottom together? *Ans.* 3 times.

19. A vessel of water is 2 feet deep: find the pressure upon each square inch of the bottom.

20. Upon a square inch of the side, 6 inches above the bottom. *Ans.* $\frac{125}{192}$ pound.

21. Upon a square inch of the side, 18 inches above the bottom.

22. In Fig. 55, if AB is 18 inches, what is the upward pressure per square inch at F? *Ans.* $\frac{125}{192}$ pound.

23. If a hydrostatic bellows be 15 inches square, and the tube be 6 feet long, when full of water how much weight will the bellows sustain? *Ans.* $585\frac{15}{16}$ pounds.

143. **Liquids rise to a Level.**—In communicating vessels or tubes, liquids rise to stand at a level. The water-works of a town illustrate this on a great scale. The water, seeking the level of the reservoir, rises from the underground pipes up into the highest stories of the houses.

An apparatus consisting of a vase, connected with various crooked glass tubes, is often used to illustrate this, but a common coffee-pot is about as good. The coffee stands at the same height in the spout as in the coffee-pot itself.

144. **Fountains, Springs, and Wells.**—It is water seeking its level that causes fountains and artesian wells. But in

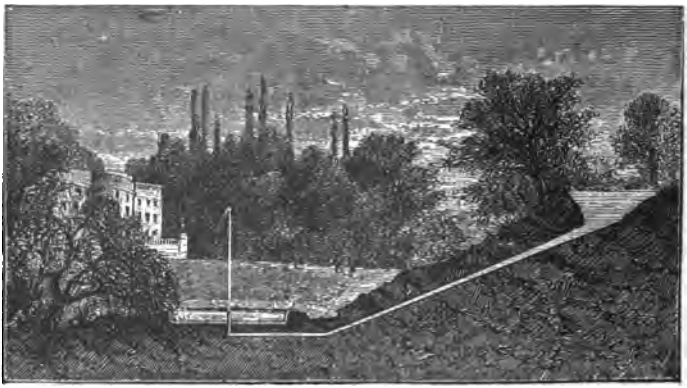


FIG. 57.—A FOUNTAIN.

a fountain the stream never rises quite so high as the level of the reservoir, on account of friction in the pipe, resistance of the air, and the interference of the falling drops with the upward stream.

When rain falls, it sinks down into the earth until it comes to a layer of rocks or clay, and flows along this to an outlet, generally where the surface of the ground sinks down to the level of the bed of clay or rock. This is a *spring*. Where there is no spring, a pit is often dug down until it reaches one of these small underground streams, and we have a *well*.

Artesian wells are small holes only a few inches in diameter, bored into the earth with a sort of auger. They are often many hundreds of feet deep, and the water rises in them, sometimes flowing out at the surface. This is because the well has tapped an underground stream of water which has flowed down there from high ground. Fig. 58 makes this clear.

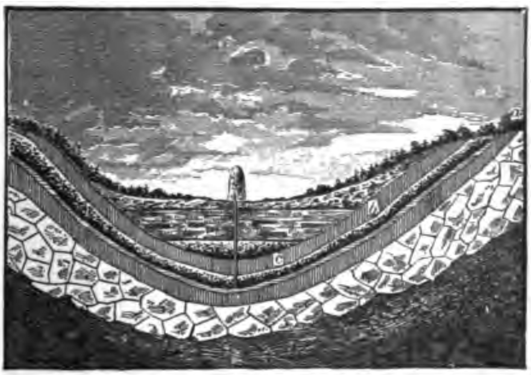


FIG. 58.—AN ARTESIAN WELL.

The water has flowed from *a* under a stratum of clay or rock, *bc*, through which the water cannot rise anywhere until the well is reached. These wells have been sunk in all parts of the world, and from some of them immense quantities of water flow.[1] Many of the oil-wells in Pennsylvania and elsewhere are artesian wells.

[1] These are called artesian because the first one was at Artois (Ar-twä′) in France.

At Passy (Päs-see′), near Paris, there is an artesian well 1923 feet deep, which discharges 5,660,000 gallons of water daily.

145. Water-Level.—The surface of a small portion of water appears to be perfectly level, and is practically so, but large surfaces of water are found to be perceptibly convex.[1] This necessarily follows from the fact that the earth is round, the water taking the shape of the earth.

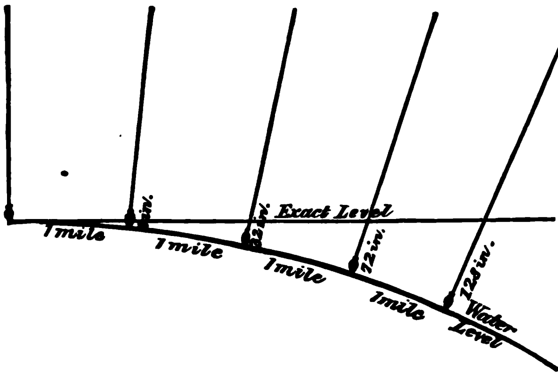


FIG. 59.—DEVIATION OF WATER-LEVEL FROM EXACT LEVEL.

The surface of water or level ground falls from a horizontal line 8 inches at the end of one mile, but 8 inches multiplied by the *square of* 2 at the end of two miles, and by the *square of* 3 at the end of three miles, etc.

Why are not the plumb-lines parallel in Fig. 59?

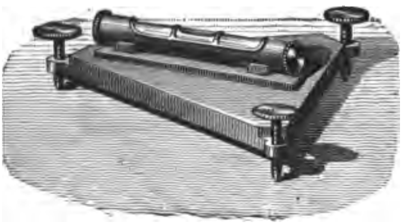


FIG. 60.—A SPIRIT-LEVEL.

146. Spirit-Level.—This very common instrument is a glass tube *almost* filled with alcohol, but with a small air-bubble left in it, and then sealed up air-tight. The tube looks to be perfectly straight, as in Fig. 60, but it is really slightly

[1] Do not forget to know clearly what *concave* and *convex* mean. You can remember that a concave surface is hollowed out like a cave, and that a convex one has just the opposite shape.

curved, as shown (but exaggerated) in Fig. 61. When the ends of the tube are level, the middle is the highest point, and the light bubble is found there. The spirit-level is constantly used by carpenters and other mechanics, and is

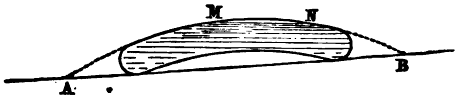


FIG. 61.—THE CURVE OF A SPIRIT-LEVEL (EXAGGERATED).

often attached to telescopes, and to surveying and other instruments.

Alcohol never freezes at natural temperatures, and is therefore the best liquid for filling levels.

147. Bodies in Water: three Important Laws.

Experiment 24.—Make a cube of wood[1] 5 centimetres (2 inches) on each side, weigh it, then let it float upon a vessel which was *full* of water. Weigh the water which ran over, and it will be found to be the same as the weight of the cube. Therefore,

I. *A body floating in water displaces its own weight of the water.*

When will the vessel weigh more, full of water, or with the wood floating in it? Try it.

Experiment 25.—Drive enough brads or tacks without heads entirely into the wood to sink it in water. Drop the cube into a vessel full of water. Catch the water which runs over in some vessel in which you can measure its volume. It will be found to be exactly 125 cubic centimetres (8 cubic inches). Therefore,

II. *A body immersed in water displaces its own bulk of the water.*

Could this principle be used to find the volume of an irregular solid, such as a bunch of keys or a watch-chain? Could you do it without making the water overflow?

Experiment 26.—Hold a stone by a string in the air, and afterwards in water; notice how much lighter it is in the water; or, more exactly, hang the weighted wooden cube by a thread to one arm of a

[1] Any piece of wood will do equally well for this experiment, but this cube will be most convenient for the succeeding ones, hence the recommendation. In order to make the experiment entirely satisfactory, the wood ought to be coated with varnish, oil, paraffin, or something of the sort, to keep it from absorbing water.

balance and weigh it. Then let it hang immersed in water and weigh it again. Its weight will be 125 grams ($4\frac{1}{7}$ ounces), the weight of a cube of water 5 centimetres, or 2 inches, on each side. Therefore,

III. *A body immersed in water is lightened by the weight of its bulk of water.*

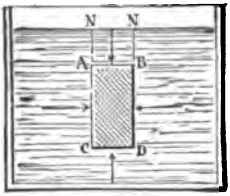


Fig. 62.

Let ABDC represent a solid block immersed in water. It is pressed *upward* at CD with a pressure equal to the weight of the column of water NCDN, and *downward* at AB by only the weight of NABN; therefore on the whole the block is pressed upward, or lightened, by the weight of the *difference* of these two columns, or ABDC.

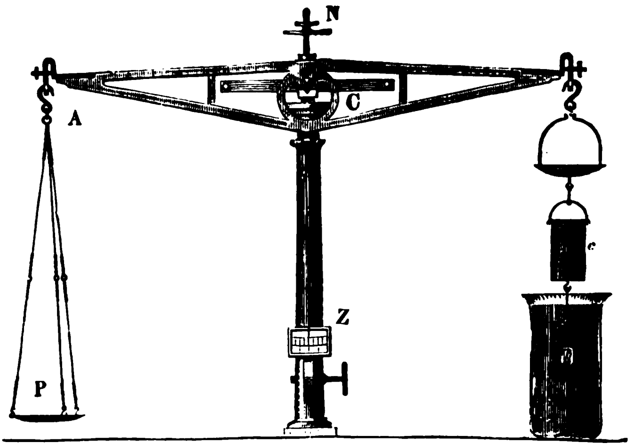


Fig. 63.—The Cylinder and Bucket Experiment.

Fig. 63 shows a piece of apparatus which illustrates this beautifully. The cylinder *p* is of solid metal, and fits into the bucket *c* exactly. The two are weighed at first with no water in the jar. Water is then poured into the jar to cover *p*, when it will be lightened, and the scale-pan *P* with the weights will fall. But if *c* be filled with water, the scales will balance again. Explain this.

148. **Floating Bodies.**—We see, then, that a body lighter than water floats because a *part* of it displaces enough

water to equal in weight the *whole* of the body. Material much heavier than water can be floated, if it is thin and hollowed out enough. A saucer or tin basin will float, although china and tin are heavier than water, because to sink it would have to displace a bulk of water equal to the shell and inside together, and this would be heavier than the shell of china or tin. It is on this principle that almost all large ships are now made of iron, and they not only float, but carry immense loads of freight.

In mechanics (Art. 93) we learned that a body stands most stable when its centre of gravity is lowest; and the same is true with a floating body. The keels of ships are often heavily weighted with metal; the heaviest part of the cargo is put in the bottom of the ship. And a ship never goes to sea empty; if no cargo can be got, it is loaded with stones for ballast.

Why is a row-boat much more apt to upset when you stand up than when you sit down in it?

The heavier a liquid, the better will a body float in it. Iron, and even lead, will float upon mercury, just as wood

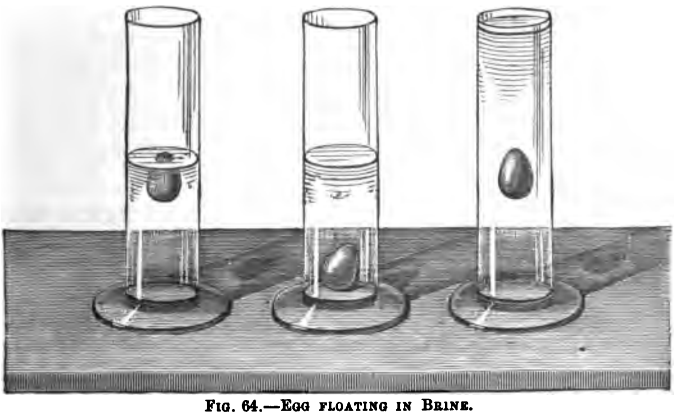


FIG. 64.—EGG FLOATING IN BRINE.

floats upon water. Sea-water is heavier than fresh water, so that a vessel sinks lower when it comes into a fresh-

water river from the ocean. And in the intensely salt water of the Dead Sea a man cannot sink if he wants to.

Experiment 27.—Fill a jar, such as is shown in Fig. 64, half full of fresh water, an egg will sink to the bottom: why?

Fill a second jar half full of strong brine, the egg will float: why?

Pour the fresh water carefully upon the brine, and the egg will sink about half-way and float there: why? Would it do to pour the salt water in upon the fresh? Try it.

SPECIFIC GRAVITY.

149. **Definitions.**—*The specific gravity of a solid or a liquid is its weight divided by the weight of an equal bulk of water.*

A cubic inch of iron weighs 4.06 ounces, and a cubic inch of water .58 ounce. The specific gravity of the iron is 4.06 ÷ .58, or 7. A cubic inch of alcohol weighs .522 ounce: what is its specific gravity?

Pure water at 39° F., the temperature at which it is densest, is the exact standard of specific gravity for solids and liquids.

The specific gravity of a gas is its weight divided by the weight of an equal bulk of air, or hydrogen, at a temperature of 32° F.

To find the Specific Gravity of a Solid.

Experiment 28.—Hang a thick screw or other small piece of iron from one scale of a delicate balance by a fine thread; weigh it carefully: suppose its weight is found to be 350 grains. Set a glass of water under it, and let the screw hang in the water; weigh it there: suppose its weight is 300 grains. According to Art. 147, 350 grains, less 300 grains, or 50 grains, is the weight of an equal bulk of water, and, therefore, 350 grains ÷ 50 grains, or 7, is the specific gravity of the screw.

Hence *the specific gravity of a solid heavier than water can be found by dividing its weight by its loss of weight when weighed in water.*

150. To find the Specific Gravity of a Solid lighter than Water.

Experiment 29.—Take a small cork, weighing, perhaps, 10 grains. Fasten it to the screw used before, and weigh the two. They will weigh 360 grains. Weigh them in the water. They will weigh less than the screw weighed in the water, perhaps 270 grains. *The cork loses all of its own weight* (10 *grains*) *and buoys up* 30 *grains of the weight of the screw.* Hence, according to Art. 147, the weight of the water equal to the cork in bulk is 40 grains. And the specific gravity of the cork is 10 grains ÷ 40 grains, or $\frac{1}{4}$.

Hence *the specific gravity of a solid lighter than water can*

be found by dividing its weight by its weight added to what it buoys up a heavy solid previously weighed in water.

151. The Specific Gravity of Liquids.—*The specific gravity of a liquid can be found by dividing the weight of a quantity of the liquid by the weight of an equal quantity of water.* Try it with strong brine, with coal-oil.

Specific gravity flasks which will hold a certain known weight of pure water at 39°, say 1000 grains, are often used to find the specific gravity of liquids. The flask is filled with the liquid whose specific gravity is to be found, and weighed. The weight of the empty flask being subtracted, the remainder is the weight of the liquid, and this divided by 1000 grains gives the specific gravity of the liquid.

Experiment 30.—Take a heavy solid, say the screw used in Experiment 28, and weigh it, then weigh it in water: suppose the weights to be 350 and 270 grains as before. Weigh it also in strong brine: suppose its weight then is found to be 256 grains. From its losses of weight in the water and brine can you find the specific gravity of the brine? How does the result compare with the specific gravity which you found for the brine before? Test coal-oil again in this way.

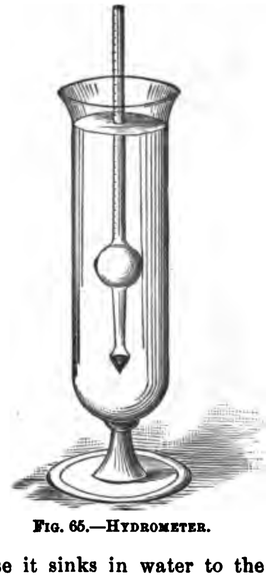


Fig. 65.—Hydrometer.

152. Hydrometers.—**Experiment 31.**—Get a piece of light wood about a foot long, and an inch square all the way along. Mark the inches and quarters of inches on one side. Bore a half-inch hole in one end, and pour it full of melted lead. Smooth the end off with knife or file, and varnish or oil the stick so that it will not absorb water. You have made a *hydrometer*.[1] Put it in water, and it will stand upright, sinking to a certain point. It will be convenient to make it sink to some inch-mark by cutting a little off one end. (If the water-mark is at first a little *above* an inch-mark, which end will you cut off? If *below*, which one? Why?) Suppose it sinks in water to the 8-inch mark. Put it in the brine. It will stand at 6¾ inches. (Why should it rise higher in the brine than in water? Do not be satisfied

[1] Hydrŏm′eter, from Greek *hudor*, water, and *metron*, measure.

until you can give the reason clearly.) Then 6⅔ cubic inches of the brine must weigh as much as 8 cubic inches of water, or 1 cubic inch of brine 1.2 times as much as 1 cubic inch of water, and the specific gravity of the brine is 1.2. With this hydrometer the specific gravities of other liquids can be quite accurately found. Try it with coal-oil or other oils, milk, or any other convenient liquid. *Glass hydrometers*, as represented in Fig. 65, are in common use. They are commonly weighted with mercury. Special instruments of this sort are often used to test milk, alcohol, acids, etc.

153. Specific Gravity of Gases.—The specific gravity of a gas can be found by weighing equal quantities of it and of air, and dividing the first by the second.

154. Capillary Attraction.—We learned in Art. 143 that

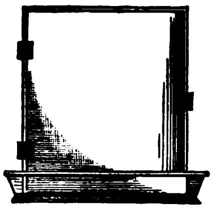


FIG. 66.—CAPILLARY ATTRACTION BETWEEN PLATES.

liquids seek a level; but there is a very curious exception to this law. If we notice the *edge* of the water in a glass vessel, we see that it rises up in a curve. If there is a corner in the vessel (as in a square inkstand), it rises higher there. If two glass plates are held in water parallel and close together, the water will be higher between them than outside; and if the plates be brought together at one end, the water will rise higher towards this end in a peculiarly shaped curve,[1] as in Fig. 66. But if the

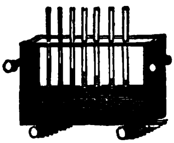


FIG. 67.—CAPILLARY ATTRACTION IN TUBES.

end of a very small glass tube be put into water, it will rise in it best of all. It is from this fact that this phenomenon takes its name of *capillary attraction*, from a Latin word (*capil'lus*) meaning *a hair*. Its cause has been given in Art. 28.

Experiment 32.—Color some water with a small quantity of indigo. Put the end of a fine glass tube (a broken thermometer tube will be good) into it, and the water will rise. If you have another finer tube, the water will rise higher in it. And if you have the simple

[1] It is proved by higher mathematics that this curve is an *hyperbola*,—a curve very familiar to mathematicians, and treated of in *Analytical Geometry*.

piece of apparatus shown in Fig. 67, you will notice that the water rises higher and higher as the tubes grow finer. And careful experiment shows that *in fine tubes the height to which a liquid will rise is just in proportion to the fineness of the bore.*

It is capillary attraction that causes a sponge to absorb water, a blotter to absorb ink, a lamp-wick to draw up oil, a towel to dry your face and hands when they are wet. If a lamp-wick or rag have one end in a basin of water and the other hanging over the side of the basin, it will slowly drain all the water out of the basin; but any impurity in the water will remain in the basin.

155. **Capillary Repulsion.**—In all the cases of capillary

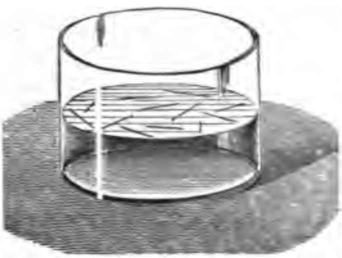


FIG. 68.—NEEDLES FLOATING ON WATER.

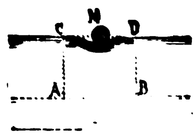


FIG. 69.—CROSS-SECTION OF A FLOATING NEEDLE.

attraction mentioned above, it will be found that the water *wet* the substance that drew it up. And *whenever there is capillary attraction, it will be found that the liquid wets the solid.* But if a glass plate be greased or waxed and dipped into water, the surface water around it will be pushed away. And if the inner surface of a capillary tube be oiled, water will sink in it below the level of the water around it. You will notice that the water does not wet the glass; and *whenever a liquid will not wet a solid,*

FIG. 70. INSECT WALKING ON WATER.

there is capillary repulsion. This is very well shown with glass tubes and mercury.

If a fine needle be greased (which can generally be done simply by drawing it between the thumb and finger), and laid carefully upon the surface of water, it will float. Fig. 69, which shows a cross-section of the needle floating upon water, explains this. The water will not wet the greased needle, but is repulsed from it, forming a trough around the needle. And the needle really displaces as much water as would fill the trough, which would weigh as much as the needle, or it displaces its own weight of water. In the same way we can explain how certain insects walk upon the surface of water.

Exercises.—1. Why do doors and window-frames swell in damp weather?

2. Why does water keep wooden buckets and tubs from falling apart?

3. In Fig. 51, *B* is 9 inches square, *A* 4 inches square. There are 4 pounds upon *A*, and it is level with *B*: what weight is upon *B*? *Ans.* $20\frac{1}{4}$ pounds. How much additional weight upon *B* will make it stand 8 inches lower than *A*? *Ans.* 23 pounds 7 ounces. If, when they are at the same height, 8 pounds be put upon *A*, how high will *B* stand above *A*? *Ans.* $13\frac{103}{125}$ inches.

4. If *B* is 15 centimetres square, and *A* is 6 centimetres square, with 24 kilograms upon *B*, what must be upon *A* to balance it? How much additional weight upon *A* will make it stand 12 centimetres lower than *B*? If, when they are at the same height, 6 kilograms be put upon *B*, how far will it stand below *A*?

5. A dam-breast is 1000 metres long, it slopes from the surface of the water to a depth of 12 metres, and the breadth of the part under water, measured slopingly, is 15 metres: what weight of water in kilograms rests upon the breast? *Ans.* 54,000 cubic metres = 54,000,000 kilograms.

6. A box 4 feet long, 2 feet wide, and 3 feet high is full of water: what is its weight? What is the pressure per square inch upon its bottom? *Ans.* $1\frac{29}{96}$ pounds. What at the bottom of one side? What half-way up one *side?* *Ans.* $\frac{125}{192}$ pounds. Half-way up one end? *Ans.* $\frac{125}{192}$ pounds.

7. Suppose a piece of sheet-iron, 2 feet wide, is run from the lower part of one end to the top of the other, in the box described in the last problem: what is the downward pressure upon the sheet-iron? the upward pressure? What is the downward pressure upon each square inch of the sheet-iron? *Ans.* $\frac{25}{48}$ pound.

8. When a hose is attached to a hydrant, why will it not throw a stream of water as high as the town reservoir? If the end of the hose is carried high enough, will the water rise *in* the hose as high as the reservoir?

9. Why are springs generally on hill-sides or in low places?

10. How many metres must a man's eye be from the ground to see 5 kilometres over water? to see 100 kilometres? *Ans.* 196+, 784.63.

11. How far out at sea could a light-house 200 feet high be seen? *Ans.* 17.32 miles. How far off could it be seen from the top of a vessel's mast 100 feet high? *Ans.* 29.56 miles. (How far towards the light-house could the surface of the water be seen from the top of the mast? Then, if one's eye were placed *there*, how much farther would it be to the light-house?)

12. Why is it easier to lift a stone under water than to lift the stone in the air?

13. The specific gravity of quartz (commonly called flint) is about 2.5. A boy can lift 120 pounds: how heavy a quartz rock can he raise to the surface of a creek? *Ans.* 200 pounds.

14. A piece of copper weighs 1100 grams, and in water it weighs 975 grams: find its specific gravity.

15. A piece of wood weighs 3 ounces; a bit of lead weighing 2 ounces in water will just keep the wood totally immersed: find the specific gravity of the wood. *Ans.* .6.

16. A water-tight box is 6 inches long and 3 inches wide. A bunch of keys raises the water in it $\frac{1}{4}$ inch: what is the volume of the keys? If your hand raises the water $\frac{1}{2}$ inch, what is its volume?

17. A cylindrical cork floats vertically with 1 inch above the water and $\frac{3}{10}$ of an inch below: find the specific gravity.

18. The specific gravity of a body is 17: find the volume of 89 ounces of it.

19. A cup when empty weighs 6 ounces; when full of water it weighs 16 ounces; when full of coal-oil it weighs $14\frac{3}{4}$ ounces: find the specific gravity of the coal-oil.

20. A wooden hydrometer, 1 inch square, sinks 9 inches in water, but 11 inches in oil: find the specific gravity of the oil.

21. A boat in a river displaces 8000 cubic feet of water; on reaching the ocean it rises so as to displace only 7800 cubic feet: find the specific gravity of sea-water and the weight of the boat. *Answers*, 1.026–. 250 tons.

22. The specific gravity of cork is .24: what is the volume and what the weight of a cork that must be attached to a piece of lead weighing 5 ounces in water, in order that both in the water may weigh 0?

23. A flask weighs 960 grains, and it will hold 2000 grains of water. Some powdered chalk weighs 50 grains in the air. When placed in the flask and the flask filled up with water, its weight is 2990 grains. Find the specific gravity of the chalk.

SECTION II.—HYDRAULICS.

156. Flow of Liquids through Openings.—We have learned in Art. 96 that, discarding the resistance of the air, a body which has fallen from any height has just the velocity with which a body would have to be sent upward to reach that height. And we also know that a fountain, if the resistance of the air and friction did not hinder it, would rise to

the level of the water in the reservoir. It must be true, then, that *water flows out of an opening with the same velocity that it would acquire in falling from the level of the water to the opening.*

Therefore the formula $v = \sqrt{2gs}$ (Art. 95) gives the velocity of discharge. This velocity does not increase, then, in proportion to the depth, but in proportion to the *square root* of the depth. In order that the liquid may flow out

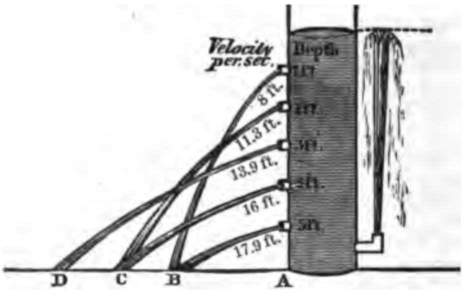


FIG. 71.—VELOCITY OF JETS.

twice as fast, the second opening must be 4 times as deep as the first, and 9 times as deep if it is to flow 3 times as fast.[1]

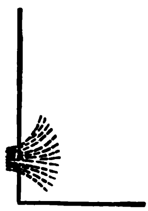


FIG. 72. — FLOW OF LIQUIDS THROUGH AN OPENING.

If an opening be made in the side or bottom of a vessel containing water, the stream which runs out will grow narrower for a little way after it leaves the opening, and then spread out again. The narrowest part of the stream is called the *vena contracta* (Latin, contracted vein). Its cause may be seen by scattering a little chalk-dust in the vessel, which will be carried along by the currents of water and show that these currents rush towards the opening from all directions, as shown in Fig. 72. And they keep on converging a little way beyond the opening and make the *vena contracta* there. On this account the quantity of water which ought to be discharged at a certain opening

[1] Before the invention of clocks, time was almost universally measured by the descent of water in a tall vessel which had a small opening at the bottom. This was called a clepsydra. If the opening is

is never reached in practice, nor is the calculated velocity ever quite reached, on account of the friction. The *range* of the spouting liquid may be found by multiplying the velocity of discharge by the number of seconds which it has to flow before striking the ground. This last is the same as the time in which a body would fall to the ground from the height of the opening. For example, in Fig. 71 the water flows from the middle orifice with a velocity of 9.8 feet per second. As this orifice is 3 feet from the ground, the time of falling from there to the ground is, by Art. 95,

$$t = \sqrt{\frac{2s}{g}} = \sqrt{\frac{2 \times 3}{32.2}} = .45 \text{ sec.}$$

$\therefore$ the range $= 9.8$ feet $\times .45 = 4.410$ feet ($= ad$ in Fig. 71).

The range from the opening 1 foot above the middle one is

$$8 \text{ feet} \times \sqrt{\frac{2 \times 4}{32.2}} = 8 \text{ feet} \times .50 = 4 \text{ feet.}$$

For the one 1 foot below the middle one we have

$$11.4 \text{ feet} \times \sqrt{\frac{2 \times 2}{32.2}} = 11.4 \text{ feet} \times .35 = 4 \text{ feet.}$$

We find here that the jet which spouts out half-way up the column of water has the greatest range of all, and the two spouting out at equal distances above and below the middle one have the same range.[1] These are universal laws, and can be rigidly demonstrated.

157. **Flow through Pipes.**—A very short pipe discharges more water from a vessel than an opening in the side of the vessel without the pipe, for the water tends to follow the side of the pipe, and the *vena contracta* is not so small. But a long pipe greatly retards the flow. A long hose-pipe

---

made just large enough to empty the vessel, after it has been filled 1 inch deep, in an hour, it must be 4 inches deep to run 2 hours, 9 inches deep to run 3 hours, 16 inches deep to run 4 hours, etc. Or the lowest hour-mark would be 1 inch high, the next 3 inches above that, the third 5 inches above that, etc., the spaces between the hour-marks increasing as the odd numbers. This depends upon the principle of falling bodies, given in Art. 94.

[1] The student may have found that, if carried out, the *second* decimal places in the second and third results will not agree. This is because the decimal places in the velocity and time of fall were not carried out far enough. If carried out, they will agree exactly. Will the resistance of the air interfere with the above conclusions?

illustrates this well. Bends in a pipe check the flow very much, and a sharp corner much more than a curved bend.

158. **Flow of Streams.**—The friction of the sides and bottom retards streams very much, otherwise all our streams would be raging torrents. Small streams may fall rapidly, but the great rivers of the world have a fall of only a few inches per mile, and flow from 2 to 5 miles per hour.

The Mississippi[1] from its source to its mouth has an average fall of but 7 inches to the mile, and in the lower half of its length of about half of this. In the last 3000 miles of its course the Amazon falls less than 1 inch per mile.

159. **Waves.**—Throw a pebble into a still pond or a puddle of water, and a wave is made which runs to the shore. The most important fact to be noticed about this wave is that, while the wave moves forward, *the particles of water do not move forward, but each particle in its turn simply moves up and down.* This can be seen by watching a chip floating in the water at some little distance from the edge. The chip will rise and fall with the water, but will not come to the shore. If, however, the chip be only a few inches from a sloping edge of the pond, it will presently be driven ashore, for the water growing shallower causes some forward motion along the shore.

It may not be easy to see how the wave can move forward while the water only moves up and down. If you will take a piece of rope and tie one end to a nail, or let a

---

[1] A question which is both interesting and profitable is often asked as to whether the Mississippi flows up-hill. As this river is in the northern hemisphere and flows from north to south, on account of the bulging out of the earth as we approach the equator (or its flattening towards and at the poles), its mouth is $2\frac{1}{2}$ miles farther from the centre of the earth than its source, and is therefore that much higher than the source. But the mouth of the river is on a much larger circle of latitude than the source, and must therefore revolve through a considerably larger circle in the twenty-four hours. This causes greater centrifugal force at the mouth, which compensates for its greater distance from the centre of the earth.

companion hold it, and, holding the other end in your hand, give it a jerk, just such a wave as has been described above will run along the rope, while each particle of the hemp has moved only up and down. And very likely you have often seen a wave, caused by the wind, run across a field of grass or standing grain, which you see must be caused in this way. The great waves of the ocean, sometimes thirty feet high, are caused by the action of the wind upon the surface of the water. Like the waves in the pond, they are, out at sea, only upward and downward motions of the water; along a sloping shore they get a forward motion, and become *breakers.* The highest part of a wave is called its *crest.* The hollow is the *trough.* The distance from crest to crest, or from any part of a wave to the corresponding part of the next one (called corresponding *phases*), is the length of the wave.[1]

If two waves were to meet each other so that the two crests met, one would be piled upon the other, and a crest higher than either would be formed. But if the crest of one meets the trough of the other it will fill the trough, and, if the waves are of the same size, smooth water will be the result.

WATER MACHINES.

160. **Water-Wheels.**—These familiar machines are of great value. In all cases their power is caused by water falling from a higher to a lower level. In the dam, or head-race,[2] which may be twenty feet above the tail-race,[2] the water has *potential* energy. In falling, its energy is *actual*, and this it communicates to the wheel, and thence to the machinery.[3] Four kinds of water-wheels are usually described.

---

[1] It is important that what is said here about waves should be clearly understood, for they play an important part later in the book.

[2] Find out what these are, if you do not know.

[3] Does the water ever get back to the dam again?

161. **The Overshot-Wheel.**—This is probably the most common of all the water-wheels. As shown in Fig. 73, in the circumference of the wheel are what are called buckets, into which the water runs from above (hence its name), and the weight of the water in the buckets turns the wheel. Some of the objections to the overshot-wheel are its cumbersomeness, the loss of water from the buckets on their way down, and its liability to freeze up in winter in Northern latitudes. Yet very many manufacturers still prefer it to any other water-wheel. Under favorable circumstances, overshot-wheels may utilize 75 per cent. of the potential energy of the water.

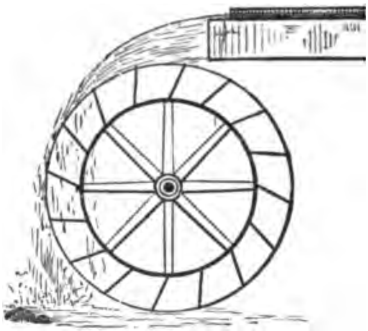


FIG. 73.—OVERSHOT-WHEEL.

162. **The Breast-Wheel.**—This wheel is shown in Fig. 74. It is sometimes used where there is but a short fall of water. Both the weight and the momentum of the water aid in producing the power. Under the best circumstances, the breast-wheel utilizes 65 per cent. of the water-power.

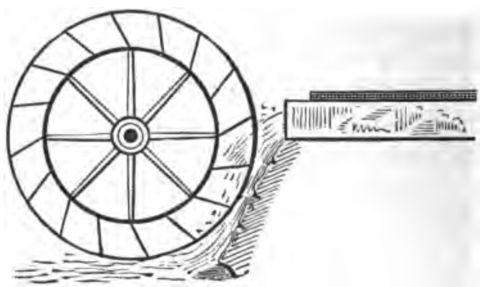


FIG. 74.—BREAST-WHEEL.

163. **The Undershot-Wheel.**—This is the most inefficient of all the water-wheels, generally utilizing only about 30 per cent. of the power. It is only adapted to streams having a strong current and but little fall, and is seldom used at all.

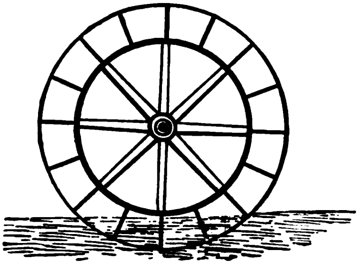


Fig. 75.—Undershot-Wheel.

Fig. 76.—Turbine-Wheel.

164. **The Turbine[1] Water-Wheel.**—This is a water-wheel of modern invention, and was first used in France. It is an iron wheel with curved paddles, as shown in Fig. 76. This wheel is set into an iron case *with its axis vertical.* Fig. 77 shows the case with the wheel inside but hidden from view. The water passes through the openings *a*, *b*, *c*, etc., in this case, and strikes the paddles of the wheel within, thus driving the wheel around. After giving all its force to the wheel, the water drops through a large opening in the bottom of the case and flows away. Unlike the first three wheels, the turbine revolves *horizontally*, not vertically.

The encased wheel is often set in an *outer* iron case, as seen in Fig. 78. This is attached to a wooden or iron tube (Fig. 79), which brings the water from the head-race.

[1] Pronounced tur′bin.

Turbine-wheels are all comparatively small. They are made as small as 1 foot or less in diameter, and are very seldom more than 6 feet in diameter. The turbine-wheels, being always entirely under water, do not freeze up in winter, and they utilize more of the power of the water, reaching 80 or more per cent. of it. On these accounts many of them are now in use, and they seem likely to supplant almost entirely the other forms of water-wheels.

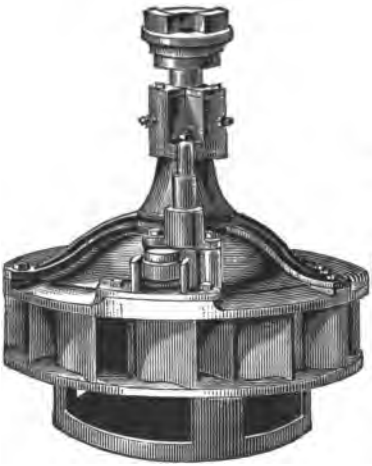


FIG. 77.—TURBINE-WHEEL IN ITS INNER CASE.

FIG. 78.—THE OUTER CASE.

165. **The Hydraulic Ram.**—This is a machine in common use for raising water. The way in which it works may be explained by reference to Fig. 80. A is a large supply-pipe leading down from a spring or other constant source of water. At C is a valve which falls down of its own weight and leaves an opening above it. When the water begins to flow through A, it escapes at C, but quickly acquires velocity enough to raise the valve there, and, by pressing it against the top, to close that opening. As the water in A is running with considerable momentum, and as the water

cannot be compressed in the lower part of the pipe (Art.

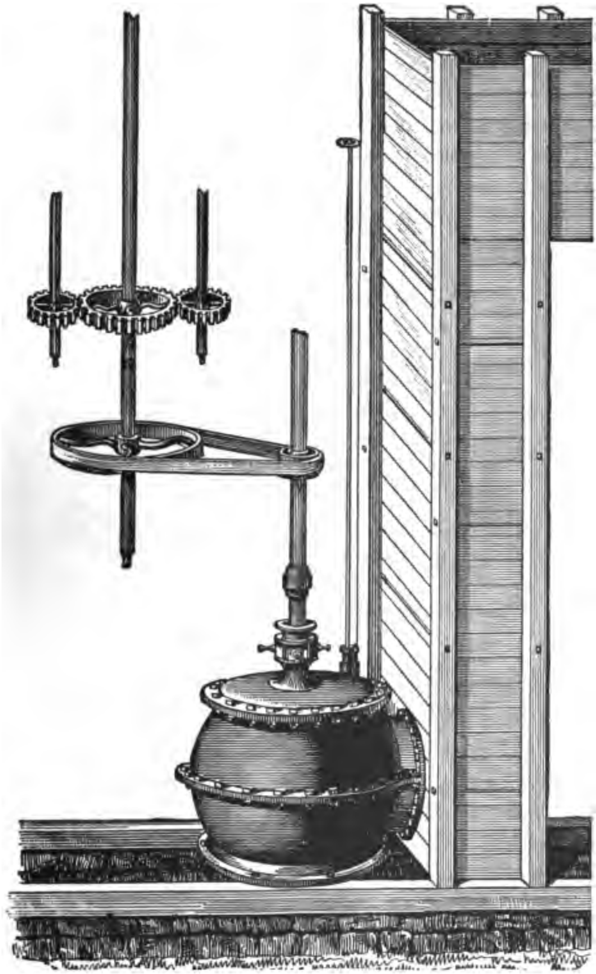


FIG. 79.—THE TURBINE-WHEEL AT WORK.

131), it lifts the valve B and rushes up into the air-chamber D, compressing the air into the upper part of the air-cham-

ber until the flow ceases. Then the valve C falls again, and the same process is repeated. The compressed air in the air-chamber, by constantly pressing upon the water below it, drives the water up the small pipe EF in a constant stream. This machine will work for months without any attention, but the water gradually absorbs and carries off the air in the air-chamber, so that occasionally a new

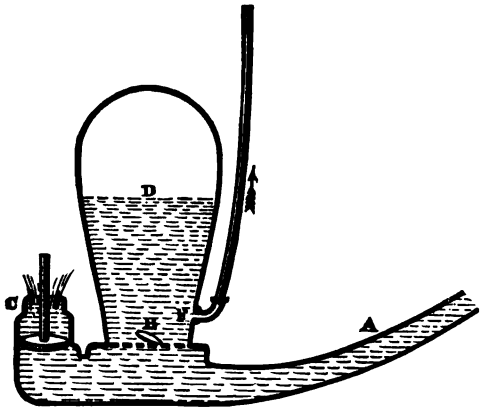


FIG. 80.—THE HYDRAULIC RAM.

supply must be admitted. The pipe A need have only a few feet of fall, and water may in this way be raised through EF to a considerable height. The repeated shock and noise caused by the lifting of C has been thought to resemble the butting of a ram, hence the curious name of this machine.

166. **Barker's Mill.**—This scientific toy is shown in Fig. 81. It consists of an upright tube, *c*, near the bottom of which are two smaller tubes extending out on opposite sides of the upright tube; near the ends of these, *but on opposite sides*, are two small openings. The pressure from the column of water in *c* is relieved at the openings, but it presses against the sides of the tubes opposite the openings,

and hence moves the machine around in that direction, or opposite to the direction in which the water spouts.

The joints of a cane fishing-pole will furnish excellent material, in the hands of an ingenious boy, to make a Barker's Mill.

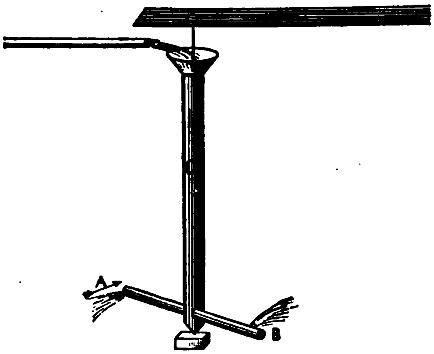


FIG. 81.—BARKER'S MILL.

Exercises.—1. Verify the velocities of the different jets in Fig. 71.

2. Find the velocity of a jet of water through an opening 10 feet below the surface; 20 feet below.

3. Find the range in each case in the preceding problem, if the surface of the water in the vessel be 30 feet from the ground.

4. Making no allowance for the *vena contracta*, how much water would be discharged through the lowest opening in Fig. 71 in 1 minute if the opening is 1 inch square and the surface of the water be kept at the same height?

Solution.— 17.9 feet = 214.8 inches, velocity per second.

$214.8 \times 60 = 12{,}888$ inches, velocity per minute.

As the jet flows 12,888 inches per minute, a column of water 1 inch square and 12,888 inches long flows out in 1 minute, that is, 12,888 cubic inches. As there are 231 cubic inches in a gallon,

$$12{,}888 \div 231 = 55\tfrac{61}{77} \text{ gallons.}$$

5. The area of the *vena contracta* is usually about $\frac{5}{8}$ of the orifice: supposing this to be the true cross-section of the stream, what would be the flow per minute in Exercise 4? *Ans.* $34\frac{67}{77}$ gallons.

6. If in Exercise 2 each opening is a circle 1 inch in diameter, how many gallons will flow out of each in 1 minute, no allowance being made for the *vena contracta*?

7. What would be the discharge in Exercise 6 if the *vena contracta* be allowed for as being $\frac{5}{8}$ of the area of the orifice?

8. Why is a stream swifter in the middle than near the banks?

9. Why does the water of a stream flow so much faster during a flood than usual?

10. What would be the effect if the water were allowed to fall upon an overshot-wheel directly over the axis?

11. Which side of the point mentioned in Exercise 10 had the water better be allowed to fall upon?

12. Why would it not do for the small pipe to open into the top of the air-chamber of the hydraulic ram?

CHAPTER IV.

GASES.

167. **Definition and Properties.**—As we have before learned (Art. 26), gas is that form of matter in which the molecules have a repellent action upon one another. A gas will expand indefinitely if it has room to do it in. A thimbleful of air, if put into an absolutely empty room, would fill the whole room. The force with which a gas tries to expand is its *tension*.

All liquids, and even some solids, are constantly, though perhaps slowly, changing to gas, which disappears by spreading itself through the air. This is called *evaporation*, and the gases into which the solids or liquids turn are called their *vapors*. By the application of heat almost every solid has been liquefied and then changed to vapor or gas. On the other hand, all the gases have by cold and pressure been changed into liquids or solids.

Until 1877, air and several other of our most common gases resisted all efforts to change their gaseous form; but in that year two European scientists, by means of great cold and enormous pressure, liquefied or solidified all of these gases which were formerly called permanent.

168. **Compressibility of Gases.**—We found that liquids were almost absolutely incompressible. Gases, on the contrary, are easily compressed.

Experiment 33.—Press a tumbler, top down, into a basin of water. As it is pushed deeper, the water can be seen to rise somewhat in the mouth of the tumbler. The pressure of the water is compressing the air. The resistance you feel is the tension of the compressed air.

169. **Mariotte's[1] Law.**—Fig. 82 shows a piece of appa-

[1] Mă-re-ot′ (1620–1684), a French scientist.

This law was first discovered by an Irish scientist, Robert Boyle

ratus used for making more careful experiments in compressing air. A little mercury is poured into the open end of the glass tube, and the air from the short end of the tube is allowed to escape by tilting the tube until the mercury stands on a level in both arms at *a*. The air in the short arm is now at its natural density, and is pressed upon only by the weight of the atmosphere itself. This weight is equal to about 30 inches of mercury, as we shall see in the next article. More mercury is now poured into the long arm, until it is about 30 inches higher there than in the short arm, when the air in the short arm (*ab*) will be found to be compressed into *one-half* its former bulk (*mb*). There is double the pressure upon it (one atmosphere of air and one of mercury), which has compressed it one-half. If one column be made 60 inches higher than the other, the air in the short arm will be compressed into the upper *third* of *ab*; it is pressed down by *three* atmospheres. 90 inches of mercury (making with the air four atmospheres) will compress the air in the short arm into *one-fourth* of its original bulk. Hence we see that *the bulk of a quantity of air is decreased just as the pressure upon it is increased.* This law is substantially true of all the gases.

FIG. 82.—APPARATUS ILLUSTRATING MARIOTTE'S LAW.

Questions.—When the mercury is 30 inches higher than *c*, is it 30 inches higher than in the short arm?

If *ab* is 6 inches, how much above *c* will the long column reach when 30 inches higher than the short one? *Ans.* 33 inches.

How many inches of mercury must be poured in to raise it as above? *Ans.* 36 inches.

What will be the answers of the last two questions if the mercury in one tube is 60 inches higher than in the other?

(1626–1691), but was afterwards independently discovered by Mariotte, and hence usually goes under his name.

170. Column of Mercury supported by the Air.—**Experiment 34.**—Take a glass tube, 1 yard long, ¼ or ⅜ of an inch in diameter, one end of which is closed, fill it with mercury, place the finger over the open end, and invert it, as shown in Fig. 83. Lower the tube until the open end is covered by the mercury in the pan below, then remove the finger. The mercury in the tube will sink until it is about 30 inches high, then it will stand there, being just balanced by the pressure of the air upon the surface of the mercury in the basin. *We have found that a column of mercury* 30 *inches high weighs the same as a column of air of the same thickness, extending from the surface of the earth to the top of the atmosphere.*[1]

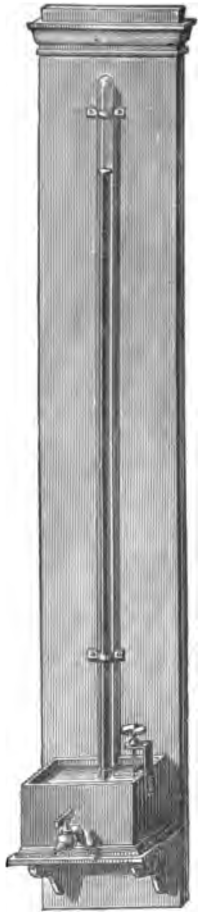


FIG. 83.—BAROMETER IN ITS SIMPLEST FORM.

When proper precautions have been taken to have the mercury pure and to remove all bubbles of air from the tube, the space above the mercury is almost a perfect vacuum. But yet there is a little vapor of mercury there. An absolute vacuum has never been made.

Why does the experiment not show that the column of mercury balances (and therefore weighs as much as) a column of air as large around as the basin? (See Art. 134.)

171. The Barometer.—If the glass tube and the basin of mercury just described be enclosed in a suitable case, and a scale of inches and fractions be made on a part of the upper end of the tube, we have a *barometer*, an instrument which will indicate the changes in the pressure (*i.e.*, the weight) of the air at that place, which makes it a very important instrument.

172. Height of Mountains measured with the Barometer.—When Pascal heard

[1] The height of the column of mercury may vary a little from 30 inches, showing that the weight of a column of the atmosphere varies.

FIG. 84.—THE MERCURIAL BAROMETER.

of the experiment described in Art. 170, he said that if it was the weight of the air that held the mercury 30 inches high in the tube, were he to carry the basin and tube to the top of a mountain the mercury would fall below 30 inches, for there would not be so much air above it there. It was tried, and, as Pascal expected, as the tube was taken up the mountain the top of the column of mercury slowly went down, a convincing proof that it was the weight of the atmosphere which was supporting the mercury. Barometers are now very commonly used to measure the heights of mountains. For low mountains the mercury falls 1 inch for about every 900 feet of height. At a height of 3½ miles the mercury is 15 inches high.[1] Half of the atmosphere is therefore within 3½ miles of the surface of the earth.

173. The Barometer and the Weather.—The most common and valuable use of the barometer is to enable us to foretell the weather: hence it is often called a weather-glass. Any sudden change in the height of the mercury is almost always followed by a storm, and usually it *falls* rapidly before a

[1] The following table shows the height of the mercury at different distances above the earth:

HEIGHT ABOVE THE EARTH.	HEIGHT OF MERCURY.
1 mile	24.7 inches.
2 miles	20.3 "
3 "	16.7 "
4 "	13.7 "
5 "	11.3 "
10 "	4.2 "
15 "	1.6 "
20 "	1 inch (or less).

storm. This will be explained and more fully discussed in the chapter on Meteorology.

174. The Aneroid Barometer.—Fig. 85 shows the aneroid barometer, very different from the mercurial barometer, and much used now. It is a thin metal box, from which the air is partly exhausted and it is then made air-tight. The top of the box is pressed down more or less, according as the pressure of the atmosphere varies; this, by means of levers, causes a hand to move back or forth, which indicates the pressure. In the figure the metal box is seen within the outside case and behind the levers. It is graduated by comparing it with a mercurial barometer. The aneroid barometer is very convenient to carry and use, for it is sometimes made no larger than a watch. It is also

FIG. 85.—THE ANEROID BAROMETER.

very delicate, but is liable to get out of order, and should frequently be compared with a mercurial barometer.

THE ATMOSPHERE.

175. **Composition of the Atmosphere.**—The atmosphere is composed mainly of two gases,—oxygen and nitrogen. These gases are not chemically united in the atmosphere, as oxygen and hydrogen are in water, but are simply mixed together in the proportion of four parts of nitrogen to one of oxygen. There is always vapor of water also in the atmosphere, as well as small quantities of other gases.

176. **Height of the Atmosphere.**—The height of the atmosphere is unknown. From calculations depending upon the duration of the twilight it was formerly supposed that the atmosphere was about 45 miles high. But this only proved that if there were air above that, it was not dense enough to cause[1] twilight. And recent observations of meteors[2] (shooting-stars) show that the atmosphere is at least 100 miles high. One-half of the whole, however, is within the first 3½ miles, and the upper part must be excessively rare.

177. **Weight of the Atmosphere.**—The atmosphere must weigh as much as an ocean of mercury covering the whole earth to a depth of 2½ feet. This is almost six quadrillion tons.[3] The air in a room 25 feet long, 20 feet wide, and 10 feet high weighs nearly 400 pounds.

178. **Pressure of the Air.**—A column of mercury 1 inch

---

[1] Twilight is the reflection of the sun's light from the upper part of the atmosphere. (Sharpless and Philips's Astronomy, p. 116.)

[2] Meteors, or shooting-stars, are small solid particles of matter moving in orbits around the sun. When these strike our atmosphere their velocity is so great that the heat produced by the blow burns them up, and it is the flash of this burning that we see. The observations referred to above show that some of them begin to burn 100 miles or more high: hence the atmosphere must extend to that height. (See Astronomy, chapter viii.)

[3] Verify this, taking 13.6 to be the specific gravity of mercury.

square and 2½ feet high weighs about 15 (14.7) pounds. Therefore the atmosphere everywhere presses down with a force of 15 pounds to the square inch. And, as is the case with water, this pressure is the same in all directions.

Everything about us is subjected to this enormous pressure. The average human body has a surface of about 2000 square inches, and therefore sustains a pressure of 15 tons. We are conscious of no downward pressure, because the air beneath presses us up just the same. And the human body, largely filled with liquids and air, is firm enough to resist the crushing pressure of 15 pounds to the square inch when distributed all over it.

179. **Experiments with the Pressure of the Air.**—Experiment 35.—Dip a tumbler under water in such a way that all the air may escape and it shall be full of water. Raise the tumbler partly out of the water, bottom upward, keeping the edge under water. Is the part of the tumbler above the water empty? Explain.

Experiment 36.—Fill a tumbler full of water. Cover the top with a card or piece of heavy paper, and, pressing this tightly against the top, invert the tumbler. Remove the hand from the card, and the upward pressure of the air will hold the card against the inverted tumbler and keep the water in it.

Experiment 37.—Make a "sucker" by taking a round piece of thick leather, fasten a string to the middle of it, wet it, and press it tightly against a brick or flat stone. As the air cannot get under the sucker, the downward pressure holds it to the brick, so that both may be lifted up by the string. Suppose the sucker stuck perfectly air-tight and had a surface of 4 square inches, how heavy a stone could be picked up with it?

Experiment 38.—Fig. 86 shows a pipette; the opening at the bottom is very small. Fill it with water and cover the upper opening with the finger, the water will not run out; remove the finger, the water will run or drop out. Why? This is much used for dropping small quantities of liquids.

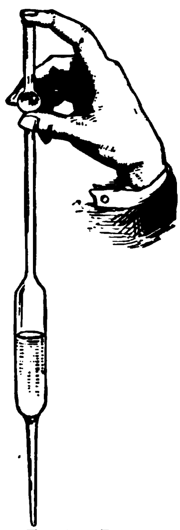


FIG. 86.—PIPETTE.

Cupping.—Physicians, in treating certain diseases, sometimes press a cup to some part of the body and exhaust part of the air from it, either by sucking it out through a tube in the bottom of the cup, or by the burning of a bunch of paper which has been put into the bottom of the cup and set on fire before it was applied to the body. The skin and flesh are sucked up into the tumbler. This shows what an outward press-

ure the body has, in order to withstand the enormous pressure of the air. (Ask your family physician to tell you all about cupping, so that you can answer your teacher's questions about it.)

180. **Stream of Air meeting a Surface.**—When a current of air strikes a surface, it does not bound off, according to the law of incidence and reflection, but follows along the surface. This is due to the adhesion of the air to the surface, and to the resistance of the surrounding air.

Experiment 39.—Blow obliquely against a wall, and while doing so hold a lighted candle so that the current would strike it were the angle of reflection equal to the angle of incidence. The flame will not be disturbed. Then hold the candle close to the wall beyond the place where the current strikes. The flame will be much disturbed, and may be blown out.

Experiment 40.—Bend a quarter of an inch of each end of a card at right angles to the card. Set the card up on these ends, as legs, upon a table, and try to blow the card over by blowing against the table under the card, with the intention of making the air rebound against the under side of the card. The air will not follow the angle of reflection, but along the table.

Experiment 41.—Take a small bent tube of glass, push one end just through a wide cork, or a piece of wood, so that the cork forms a little platform about the end of the tube. Put a pin through a card, and lay the card upon the cork, letting the pin run into the tube. Now blow into the other end of the tube. The card will not be blown off, but will stick tight to the cork, and, if turned upside down, will stay there as long as the blowing lasts; when that stops it will fall off. The air flowing out in all directions between the cork and the card produces a partial vacuum there, and the pressure of the air on the other side of the card causes it to stick closer.

181. **Buoyancy of the Air.**—All bodies in the air are buoyed up by it, just as they are when in water, and are of course lightened by the weight of the air displaced. This is about 1 ounce for each cubic foot of the body's bulk, and is not therefore noticed except with very light substances, such as feathers and the like.

182. **Balloons.**—These are huge bags of silk, made air-tight by varnish, and filled with hydrogen or, more commonly, with common illuminating gas. As either of these is much lighter than air, the balloon will ascend and carry considerable weight with it. In 1862, Mr. Glaisher (glā'-

sher), of England, ascended in a balloon to the enormous height of 35,000 feet, or nearly seven miles.

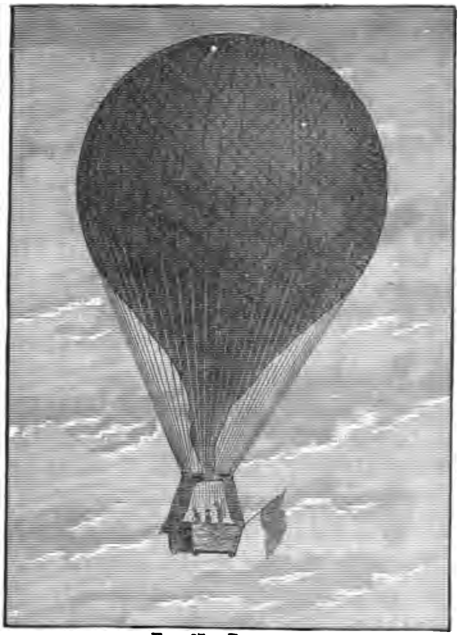


FIG. 87.—BALLOON.

PNEUMATIC MACHINES.

183. **The Bellows.**—The common hand-bellows is made of two tapering boards, joined together around the edges by flexible leather, and having a nozzle at one end. An opening in one of the boards is covered on the inside with a flap of leather fastened only at one end. This is a *valve;* it opens freely inward. When the sides of the bellows are pushed apart, the air pushes the valve inward and rushes in. But when the sides are brought together, the air pushes the valve tight against the side, and, thus closing that opening, must escape through the nozzle. The stream of air is not continuous.

Blacksmiths use an improved bellows, which gives a continuous stream of air. When one lets go of *a*, the lower board falls and the air pushes the valve *v* up and rushes in. When *a* is pushed down and *bc* raised, *v* closes and the air is forced through *v'* into an upper chamber. Upon this there are weights which constantly force the air out of the nozzle.

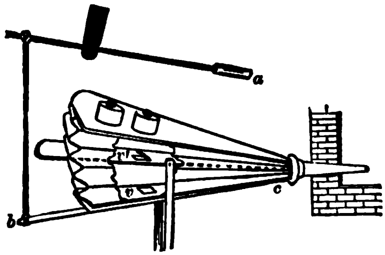


FIG. 88.—BLACKSMITHS' BELLOWS.

184. The Air-Pump.—This very useful machine was invented by Otto Guericke[1] about 1650. Fig. 89 gives a complete view of one of the simpler forms of the machine, and Fig. 90 shows the inside of one. In the common ones the rod running up from S' is wanting. *ab* is a brass cylinder, called the *barrel*, in which an air-tight piston, *p*, moves up and down. When *p* is raised from the bottom of the cylinder, a vacuum is formed below it, and the tension of the air in the receiver E causes it to rush along the tube below, to push up the valve S', and to fill the cylinder with rarefied air. When the piston is pushed down, S' falls, and the air pushes S up in order to escape. One barrelful has been pumped out of the receiver. The next time a barrelful of rarer air is taken out, and that left in E is rarer. This can be kept up until the air in E is very rare, until it is so rare that its tension is too feeble to lift the valve S', but it is evident that it can never be entirely exhausted.

Some of the more expensive air-pumps have the rod shown in Fig. 90, by means of which the piston opens and closes the valve S'. As seen in the figure, the rod passes through the piston, fitting in it rather tightly. When the piston is pushed down, the rod sticks fast

[1] Otto von Guericke (fon ga'rik-eh), a German natural philosopher, 1602–1686.

in the piston until S′ is pushed down, then the piston slips down

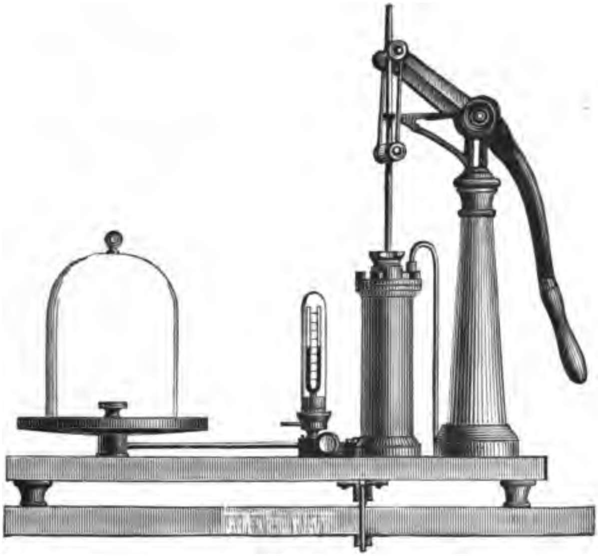


FIG. 89.—THE AIR-PUMP.

around it. When the piston is raised, it lifts the rod high enough to open S′, but cannot lift it farther, because of the button at the top of

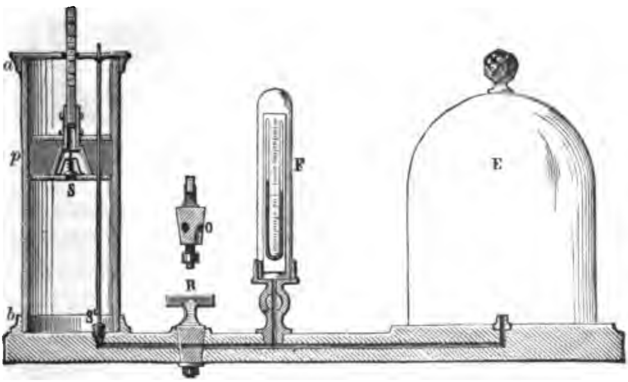


FIG. 90.—THE INSIDE OF AN AIR-PUMP.

the rod. Since the action of the valve S′ does not depend upon the

tension of the air in the receiver, this pump will produce a more nearly perfect vacuum ; but it is evident that this could not produce an absolute vacuum, and the impossibility of making perfect machinery renders the vacuum appreciably less perfect than in theory it ought to be.

Air-pumps are often made with *two* barrels, in order to exhaust the air more rapidly; and many different forms of the machine have been devised for the same purpose.

185. **The Air-Pump Gauge.**—In Fig. 90, F is a gauge to show how much of the air is exhausted. It is a U-shaped tube, closed at one end, containing mercury, and enclosed in an air-tight glass case, into which there is an opening from the receiver. Before the pump begins to work, the mercury is all standing in the closed end of the tube, which it fills to the top, and is kept there, of course, by the pressure of air down the open end, which is the same then as the pressure of the air outside. When part of the air has

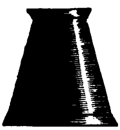


FIG. 91.—HAND-GLASS.

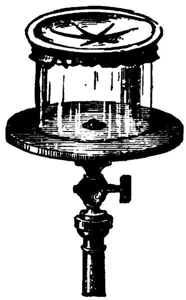


FIG. 92.—THE BURST BLADDER.

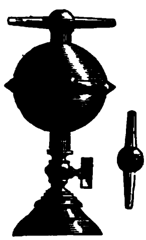


FIG. 93.—MAGDEBURG HEMISPHERES.

been exhausted, the tension of the air in the pump is not great enough to hold up the mercury in the closed tube, and it gradually falls. If a perfect vacuum were made, the mercury would, of course, stand at the same height in both tubes. The branches of the tube are usually only a few inches long, as the gauge is not needed until most of the air is exhausted.

Another form of gauge is sometimes made by attaching

a long glass tube to the air-pump by a rubber tube, and then putting the lower end of the glass tube in a vessel of mercury. As the air is exhausted, the mercury will rise in the tube.

How high would it rise if the pump could produce a perfect vacuum?

186. **Experiments with the Air-Pump.**—**Experiment 42.**—Take a *hand-glass* (Fig. 91), and set it upon the brass plate of the air-pump, in the place of the receiver.[1] Cover the top of the glass closely with one hand, and work the pump. As the air below is exhausted, the pressure of the air above is felt, and presently it becomes difficult to remove the hand from the top of the hand-glass.

Experiment 43.—Tie a piece of wet bladder tightly around the top

FIG. 94.—THE WEIGHT-LIFTER.

FIG. 95.—WEIGHT IN A VACUUM.

of the hand-glass, or around the top of a bladder-glass; after drying it thoroughly, put it upon the air-pump, and exhaust the air, the bladder will burst with a loud report: which way, inward or outward?

Experiment 44.—The Magdeburg hemispheres are two hollow brass hemispheres, which will fit very closely together. After cleaning and greasing the edges, put the hemispheres together, and screw fast to the air-pump. After exhausting the air, turn the stop-cock,

[1] Here, as in all experiments with the air-pump, unless the lower edge of the glass vessel is carefully ground, it must be coated with tallow, to keep air from passing between it and the brass plate. The edge of the glass and the brass plate should be cleaned beforehand.

remove from the air-pump, and screw on the second handle. Two students will find that they may pull hard, yet not pull the two hemispheres apart. Turn the stop-cock, and they fall apart:[1] why?

Experiment 45.—Put a foot-ball *partly* filled with air, or a partly-blown bladder, under the receiver of an air-pump. Exhaust the air, and the foot-ball or bladder will swell out: why? Try the experiment with raisins or a shrivelled apple under the receiver.

FIG. 96.—FOUNTAIN IN A VACUUM.

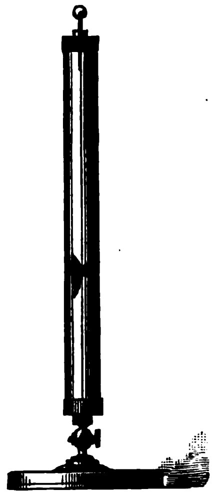


FIG. 97.—FEATHER AND COIN.

Experiment 46.—"Bursting bombs," air-tight cubes, or flasks of thin glass may be bought from any dealer in philosophical apparatus. Put one under the receiver, and exhaust the air. It will burst with considerable force. Explain.

Experiment 47.—Attach the top of the *weight-lifter* (Fig. 94) to the air-pump by a rubber tube. Exhaust the air, and the weight will be drawn up: why?

Experiment 48.—Carefully balance a good-sized light metal ball, then put it under the receiver, and exhaust the air. The ball will now be found to be heavier than the weight: why? (See Art. 181.) For this experiment a hollow metal ball is commonly used. Should there be an opening into the ball? Any light solid or liquid, such as a glass

[1] The Magdeburg hemispheres were invented by Otto von Guericke, the inventor of the air-pump. The hemispheres get their name from the city in Germany where the inventor lived. He made a very large pair, and in an exhibition before the Emperor of Germany it is said that several horses were unable to pull them apart.

bottle (should it be stoppered?), may be thus weighed outside and then inside the vacuum. Why ought the body weighed to be lighter (less specific gravity) than the weights used? Suppose it were the *same* as the weights? Suppose it were *heavier?*

Experiment 49.—Unscrew the top of the vacuum fountain apparatus (Fig. 96), screw it to the air-pump, and exhaust the air. Turn the stop-cock crosswise, and screw it into its base again. The pan at the bottom is filled with water, into which a tube, running up the stem, opens. If the stop-cock be turned, the water will rush up into the glass vessel in a fountain: why?

Experiment 50.—Fig. 97 shows a long, air-tight glass tube containing a feather and a small coin. Turn the tube upside down, and the coin will fall quickly to the other end, but the feather will lag slowly behind. Exhaust the air from the tube, and try the same thing. They will fall together: why? (Art. 181.)

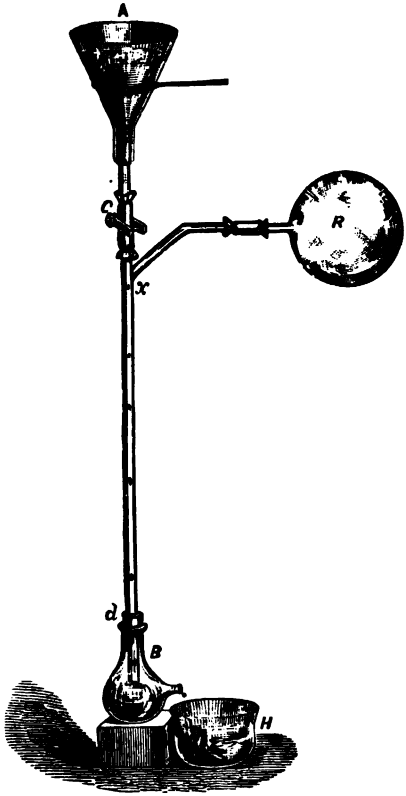


FIG. 98.—SPRENGEL'S AIR-PUMP.

187. Sprengel's Air-Pump.—The imperfections of the common air-pump have already been mentioned. A *very* good one will leave $\frac{1}{1500}$ of the air in the receiver. But Fig. 98 represents a much more perfect kind of air-pump. The funnel A contains mercury. The long, narrow glass tube *cd* opens into the funnel and dips at the lower end into the mercury in the bottle B. The receiver R, from which the air is to be exhausted, has air-

tight connections with the tube. The mercury running down the tube from the funnel separates into drops, *because its velocity increases as it falls.* Each drop is an air-tight piston, and between the drops are nearly perfect vacuums. As one of these vacuums comes to x, part of the air in R rushes out to fill it, and that air is carried down into the bottle B, where it comes to the surface as a bubble and disappears. In this way the air is drawn from R until almost a perfect vacuum is formed there. Under favorable circumstances, this pump leaves only $\frac{1}{1,000,000}$ of the air in the receiver.

As the exhaustion goes on, the mercury stands higher and higher in the tube, and finally is about 30 inches above the spout B. (Why?) With no intervening air-spaces, the opening x must therefore be more than 30 inches above the spout B. The whole apparatus is commonly about 6 feet high, and the upright tube is about $\frac{1}{10}$ of an inch in diameter. The process is slow, especially if the receiver be large. It is only by this pump that the necessary vacuum can be produced in the electric lamp of the present day.

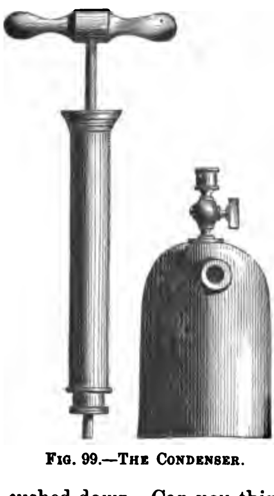


FIG. 99.—THE CONDENSER.

188. **Air-Condenser.**—If the two valves in the barrel of the air-pump (Fig. 99) were turned the other way,—that is, if both opened *downward* instead of upward,—it is clear that every stroke of the piston would drive air *into* the receiver. Such a piece of apparatus is called a condenser.

Draw a section of a condenser showing the position of the two valves while the piston is being raised. Draw another showing them while it is being pushed down. Can you think of any way in which a condenser could be made with its piston solid, and having then a valve only at the bottom?

189. **Experiments with the Condenser.**—If the reservoir be partially filled with water, and a tube runs from under the surface of the water into the air, the water may be forced out by compressing air above it. Many of the experiments with the air-pump may be reversed with the condenser. A foot-ball or bladder may be shrivelled. (How?) A thin cube of glass may be crushed. The specific gravity of air or any other gas can be best found by compressing a considerable quantity of it in a receiver and then weighing it. (Art. 168.)

190. **The Air-Brake.**—This very useful invention consists of a powerful condenser attached to a locomotive, and working by steam. It is connected by rubber tubes with a reservoir under each car, and fills these reservoirs with highly-compressed air. When the engineer wishes to stop the train, he moves a lever, which allows the compressed air in the reservoir to rush into a cylinder, also under the car, and, by driving a piston along this cylinder, it presses the brakes very strongly against the wheels.

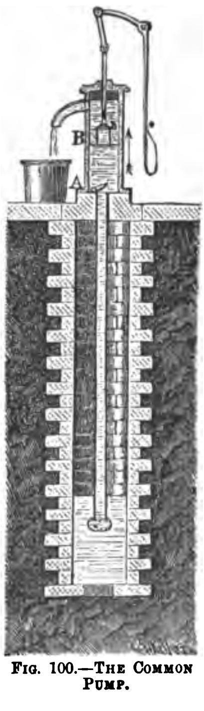


FIG. 100.—THE COMMON PUMP.

191. **The Common Pump.**—Fig. 100 shows the common pump. It consists of a tube (pump-stock), in which works a piston having in it a valve opening *upward*. Opening into the bottom of this there is a narrower tube, which runs down into the water. At the top of this tube is another valve, also opening upward. To show how it works, suppose that no water is standing in the pump. When the piston moves up from the bottom of the pump-stock as *its* valve remains closed, it tends to form a vacuum

below it. The atmospheric pressure upon the surface of the water in the well drives up water, and the air in the tube above it, to fill this vacuum. When the piston descends, the lower valve falls, and keeps there the air and water that have been drawn up from below, and the valve in the piston opens to allow the piston to pass through this air and water in the pump-stock. The next stroke of the piston raises the air and water above it to the spout, and the water rises from the well as before to fill its place. And at each successive stroke the pump-stock full of water is pumped out.

If the valves are tight, the tube and pump-stock are usually standing full of water, so that the latter begins to flow at the first upward stroke.

192. **Depth from which Water may be raised by the Common Pump.**—We have found that the atmosphere will sustain a column of mercury 30 inches high; and, as mercury is about 13½ times as heavy as water, the atmosphere will sustain a column of water 13½ times 30 inches high, or about 34 feet. Since the atmospheric pressure will raise water 34 feet, if a pump were perfectly made it would work as long as the *upper* valve was within that distance from the bottom of the well. Practically, however, the upper valve ought never (*i.e.*, at the upper end of the stroke) to be more than about 25 or 26 feet from the surface of the water.[1] Water can be raised farther than that by having the upper part of the pump-stock lengthened so

---

[1] It was through the observation of this fact that Galileo (gal-i-lee′o) (great Italian astronomer and philosopher, 1564–1642) first suggested the true cause of water rising in a pump. It had formerly been explained by saying that nature abhorred a vacuum and therefore the water rose to fill the vacuum caused by the piston. The Grand Duke of Tuscany wished to pump water from a depth of 40 or 50 feet, but the pumps would not work. Galileo found that the water would rise but 32 feet, and suggested that it was the weight of the atmosphere that supported the water at that height. His pupil Torricelli (1608–1647) afterwards discovered that the atmosphere would support 30 inches of mercury, as explained in Art. 170.

as to bring the spout some distance above the upper end of the stroke of the piston. The piston then *lifts* the water above it to the spout.

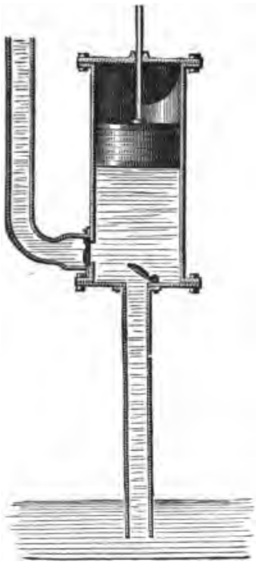


FIG. 101.—A FORCE-PUMP.

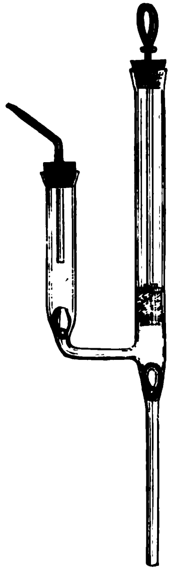


FIG. 102.—MODEL OF A FORCE-PUMP WITH AIR-CHAMBER.

193. **The Force-Pump.**—To raise water higher than 26 feet, force-pumps are often used. Fig. 101 represents a simple kind. The piston is solid. The up-stroke draws the water from the well and fills the pump-stock with it. The down-stroke closes the lower valve and forces the water through the side-valve and up the pipe seen there.

194. **Force-Pump with Air-Chamber.**—Sometimes force-pumps are furnished with air-chambers to cause a continual flow of water. Fig. 102 shows a model of such a pump. The water is forced up into the tube which branches off to the left, and compresses the air there into the upper

part. This presses upon the surface of the water and drives it in a constant stream through the small tube.

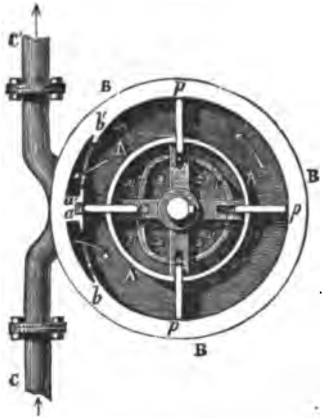


FIG. 103.—ROTARY PUMP.

195. **Rotary Pump.**—To supply cities with water, to empty mines, and wherever large quantities of water must be raised, rotary pumps are often used. They are made in many ways, one being shown in Fig. 103. It is a round iron box, in which four paddles turn. These suck the water up the lower tube and drive it up the upper one.

196. **Fire-Engine.**—Fig. 104 represents a common hand fire-engine. It has two force-pumps, which drive the water

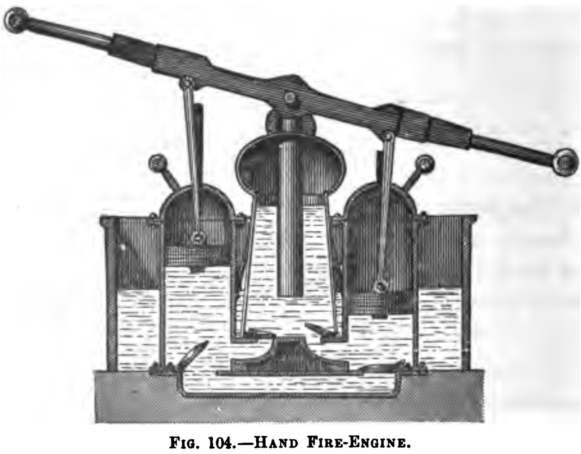


FIG. 104.—HAND FIRE-ENGINE.

into an air-chamber between them, whence it is forced out through the hose by the pressure of the compressed air.

The water is usually supplied by being carried in buckets, and the pumps are worked by several men. The steam fire-engine is a powerful steam-pump, generally rotary, which draws its water through a hose from some artificial or natural reservoir, and drives it out with great force through another hose.

197. **The Siphon.**—If a tube open at both ends be bent, as in Fig. 105, having one arm longer than the other, we have a *siphon*. If this be filled with water, and then be placed, as in the figure, with *the short arm* in a vessel of

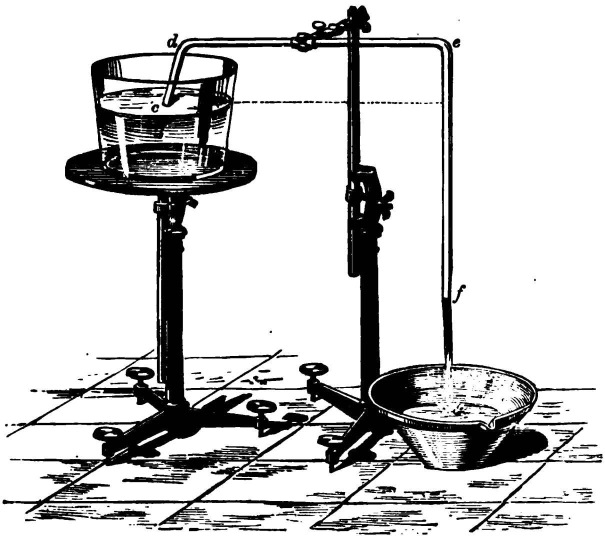


FIG. 105.—A SIPHON.

water, the water in the tube will, of course, tend through gravity to flow down, and out of, both arms of the tube; but this it cannot do, because it would leave a vacuum above. And as the long column, *ef*, is heavier than the short one, *dc*, the water runs *down* the long arm, and that in the vessel flows *up* the short arm (through the pressure

of the air upon the water in the vessel) to fill the vacuum there, and in this way the vessel may be emptied of the water.

198. **Starting the Siphon.**—It is evident that the siphon will not start itself. It may be filled by putting it under water, and then both ends must be closed by the fingers

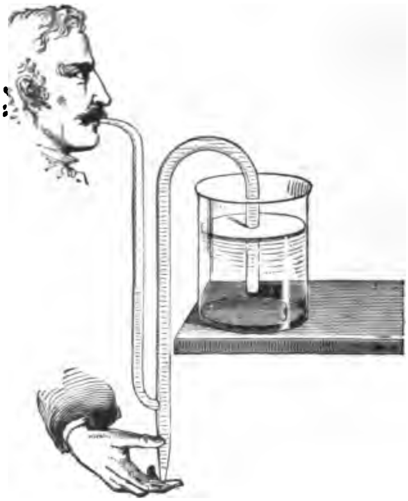


FIG. 106.—A SIPHON WITH EXHAUST-TUBE.

until it is in position. Or it may be put in position empty and filled by sucking at the end of the long arm. Where this cannot be done, or is undesirable, the siphon can have a suction-branch, as in Fig. 106.

Why is the end of the siphon kept closed by the finger in starting it? Will it be necessary to suck the long arm *full* before the siphon will begin to run?

199. **Uses and Limitations of the Siphon.**—The siphon is often used to empty vessels of liquids. It may be used to carry the water from a spring over a low hill to a house or a barn which is below the level of the spring.

The end of the tube from which the liquid flows must always be below the surface of the liquid in the vessel. If the surface should

be lowered until it is on the same level with the outlet, the flow will stop. As atmospheric pressure will not raise water more than

FIG. 107.

FIG. 108.—TANTALUS'S CUP.

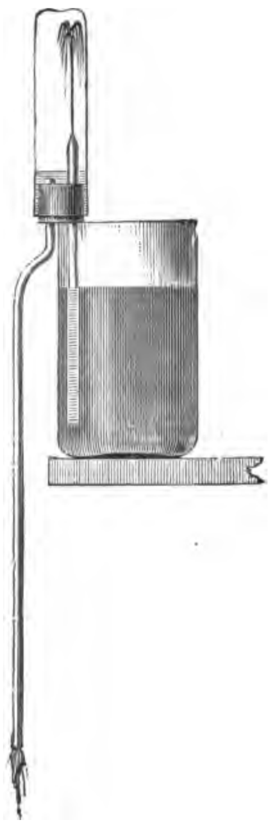


FIG. 109.—SELF-ACTING FOUNTAIN.

34 feet, if water is to be siphoned, the top of the curve must not be more than 34 feet higher than the surface of the water.

200. Experiments with the Siphon.—**Experiment 51.**—Fig. 107 represents a vessel with a closely-fitting lid which has two openings in it. Through a cork fitting one of these openings runs a siphon-tube. After being started, the water in the vessel will flow, but will stop when the other opening in the lid is stopped by the finger: why?

Experiment 52.—Fig. 108 represents the "cup of Tantalus." It will be noticed that the handle is a siphon, the short arm of which opens into the bottom of the cup. When the cup is filled full, or when it is tilted so as to bring the water up to the highest part of the handle, the water will begin to run, and will empty the cup.

Fig. 109 shows how a self-acting fountain can be made of the bottom of a glass bottle, a cork, and two glass tubes. A dandelion-stem will make a good siphon. Try it.

201. Intermittent Springs.—These are springs which flow only at intervals. They have been explained on the principle of the siphon. Fig. 110 shows how this may be. If a reservoir in the earth had such a siphon-shaped outlet as is there shown, when it filled up to the bend of the outlet,

the water would run until the reservoir was emptied, and then would cease running until filled up to the bend again.

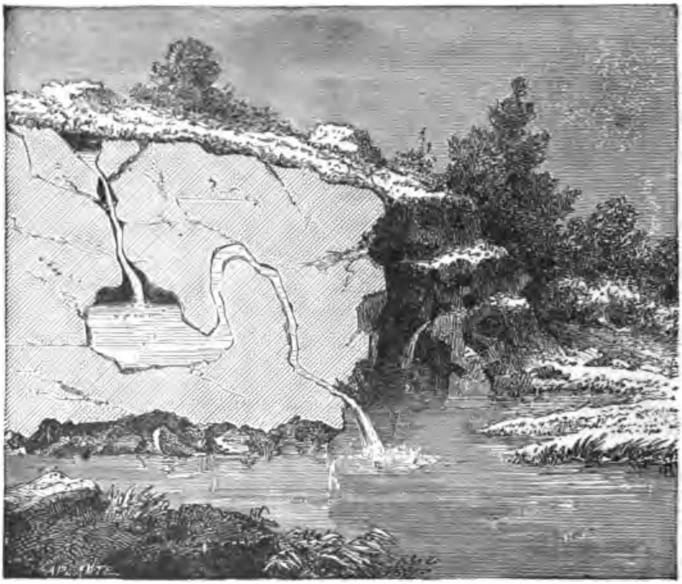


FIG. 110.—THE INTERMITTENT SPRING.

Exercises.—1. In Fig. 82 the mercury stands 90 inches higher in the long tube than in the short one. If *ab* equals 6 inches, how many inches of air are there below *b*? *Ans.* $1\frac{1}{2}$ inches.

2. How many inches of mercury have been poured in to condense this? *Ans.* 99 inches.

3. If one column is 20 inches higher than the other, what is the length of the air-column in the short arm? Since the pressure is $1\frac{2}{3}$, or $\frac{5}{3}$ as great as before, the air will occupy $\frac{3}{5}$ as much space, or $3\frac{3}{5}$ inches.

4. If one column is 10 inches higher than the other, what is the length of the air-column in the short arm? *Ans.* $4\frac{1}{2}$ inches. What if it is 45 inches higher?

5. The specific gravity of mercury is 13.6, that of alcohol is .8: how high a column of alcohol will the atmosphere support? *Ans.* 42 feet 6 inches.

6. How high a column of sulphuric acid, whose specific gravity is 1.8, will the atmosphere support?

7. A tumbler whose sides are vertical is inverted and pushed down into water until the air is condensed into the upper half of the

tumbler: how deep is the tumbler? *Ans.* 34 feet. Is it the bottom, the middle, or the top of the tumbler that is 34 feet deep?

8. How deep must the tumbler be if the air is compressed into the upper third of it? *Ans.* 68 feet. How deep if it is compressed into the upper fifth of the tumbler?

9. How high will the barometer stand at a place 1800 feet above the sea?

10. Barometers are often marked FAIR opposite $30\frac{1}{2}$ inches, CHANGE opposite $29\frac{1}{2}$ inches, RAIN opposite $28\frac{1}{2}$ inches, etc. If a person were to buy such a barometer and take it to a place 900 feet above sea-level, what would be the result? what if he lived in a place 1800 or 2700 feet above the sea?

11. Explain how you fill your lungs with air.

12. How do you suck water through a tube?

13. Why will a liquid flow out of the spigot of a barrel so much faster when the bung at the top is out?

14. Why does water gurgle and flow so irregularly when poured out of a bottle?

15. Why will water flow through a funnel so much better when the funnel is raised a little in the mouth of the bottle which you are filling with water?

16. What part of the air is left in the receiver of an air-pump when the mercury in the gauge is 3 inches higher on one side than on the other? *Ans.* $\frac{1}{10}$. When $\frac{1}{2}$ inch higher?

17. What is the difference of heights in the gauge when $\frac{1}{1500}$ of the air is left in the receiver?

18. A pair of Magdeburg hemispheres have a diameter of 3 inches. If the air were perfectly exhausted, what force would it take to pull them apart? *Ans.* 106 pounds.

19. Otto Guericke's hemispheres are said to have been 2 feet in diameter. Had he been able to exhaust all the air, what force would have been needed to pull them apart? It is sometimes said that 30 horses, 15 on each side, were unable to pull them apart. Can that be true?

20. If the inside diameter of a weight-lifter is 6 inches, what weight will it lift, provided a perfect vacuum be produced?

21. How heavy a stone will a perfect "sucker," 4 inches in diameter, lift?

22. What is the difference in the heights of the columns of the air-pump gauge when, by using Sprengel's pump, only $\frac{1}{1,000,000}$ of the air is left in the receiver? *Ans.* .00003 inch.

23. Bunsen's air-pump uses falling water as Sprengel's does falling mercury: how long must the tube below x be?

24. Denver, Col., is about 1 mile above sea-level: how high would a perfect pump raise water there? *Ans.* 28 feet. (See foot-note, p. 98.)

25. If a certain pump will raise fresh water 25 feet, how high will it raise salt water?

26. The diameter of the piston of a pump is 2 inches, and the height of the top of the water in the pump above the piston is 18 feet: what is the pressure upon the piston?

27. What will be the pressure upon the piston in the last problem if the diameter of the upper 10 feet of the column of water is 3 inches?

CHAPTER V.

SOUND.

SECTION I.—THE CAUSE AND PHENOMENA OF SOUND.

202. **Sound is a Vibration.**—All sound is caused by the vibration of some body. When a violin-string is sounded, the vibrations can be seen. If a tuning-fork be sounded, and the fork be touched to the lips or teeth, the vibrations can be felt.

Experiment 53.—Fasten, with wax, a short bit of fine wire, or a bristle, to the end of one prong of a tuning-fork. Sound it by striking it against the table, and draw the end of the wire gently over a piece of smoked glass. The vibrations of the fork will trace a beautiful wavy line on the glass.

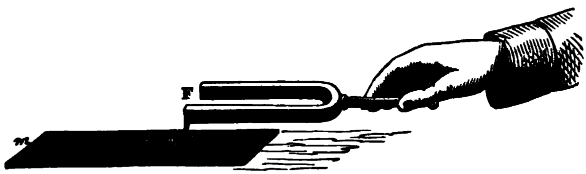


FIG. 111.—TUNING-FORK RECORDING ITS VIBRATIONS.

The word sound is used in two senses. It is sometimes used to denote *the vibration of the sounding body*, but is oftener used to denote *the effect of this vibration upon an organ of hearing.* Accordingly, when the old question, "If a tree were to fall in a forest fifty miles from any living being, would there be any sound?" is asked, the answer depends upon which definition of sound is taken.

203. **Sound usually brought to the Ear by Vibrations of the Air.**—As sound is always caused by the vibrations of some body at a distance from the ear, there must be some way by which it is carried to the ear. This is almost

always done by vibrations of the air, as may be shown by the following experiment.

Experiment 54. — Set a small clock, or a music-box, under the receiver of an air-pump, taking care to put under the clock a number of thicknesses of flannel. Exhaust the air, and the ticking of the clock, or the sound of the music-box, will grow fainter and fainter, until it can no longer be heard.

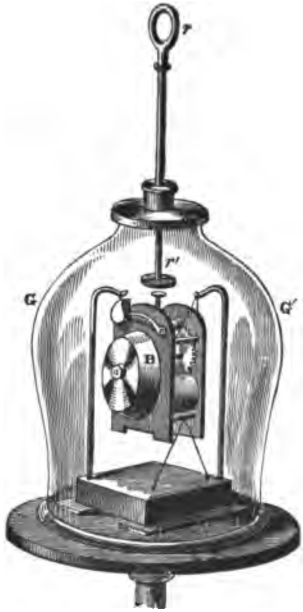


FIG. 112.—BELL IN A VACUUM.

Fig. 112 shows a bell which can be kept ringing by clock-work, and is hung by cords in the receiver of an air-pump, which is often used to prove this fact. Here, as also above, the experiment is more satisfactory if, after the air is exhausted as far as possible, the receiver be filled with hydrogen and again pumped out. Fig. 113 is a simpler piece of apparatus to illustrate the same thing.

On the tops of high mountains sounds are considerably fainter than upon the surface of the earth: why?

204. **How Air conveys Sound.**—Suppose a tuning-fork be sounded and held at one end of a tube, as shown in Fig. 114. As the prong of the fork flies out, it will drive the air that is in front of it forward a little way and compress it. This air will condense and drive forward the air in front of it, and so the condensation will be driven through the tube. *Any one particle of air moves forward only a very little way, when it gives its motion to the particle ahead of it, but the condensation, or the wave, moves through the whole tube.* Sound-waves are just like water-waves, as described in Art. 158, except that in sound-waves the particles of air move

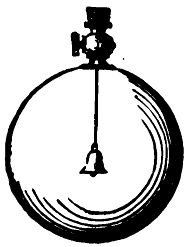


FIG. 113.—BELL IN A VACUUM.

lengthwise, but in water-waves the particles of water move up and down.

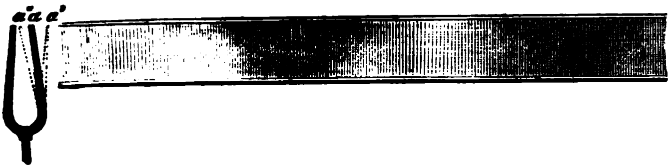


FIG. 114.—SOUND-WAVES IN A TUBE.

The sound-wave is not a puff or blast of air, such as you blow from your mouth. Tyndall[1] has shown this very neatly by the following experiment.

Experiment 55.—Fill the long tube shown in the figure with smoke from burning paper, set a lighted candle at one end, and make a loud noise, by clapping two blocks together, or otherwise, at the other end. The flame will be put out, yet no blast of air rushes through the tube, for the smoke has not been driven out.

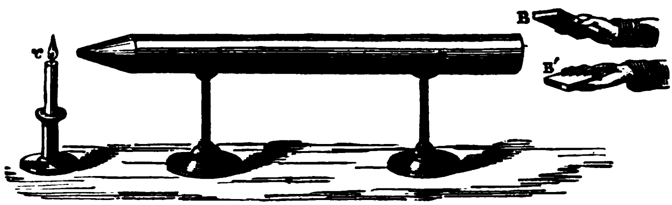


FIG. 115.

In the open air these condensations move in all directions. Each one must therefore be a spherical shell, growing larger as it moves farther in every direction from where the sound was made. Following every condensation there must of course be a rarefaction. And so these successive waves of condensation and rarefaction are constantly given out in all directions as long as the sounding body vibrates.

[1] John Tyndall (1820–), an English natural philosopher, and one of the greatest of living scientists. "Tyndall on Sound" is the best book on this subject in the English language for most readers and students.

205. Velocity of Sound in the Air.—Every one who uses this book has probably noticed that when a whistle, some distance off, is blown, the escaping steam can be *seen* a little time before the sound can be *heard*, and that the sound keeps coming just as long after the steam can be seen to have stopped. And when a wood-chopper is working at a considerable distance, you hear the blow after you see it. As we shall presently learn, light travels so exceedingly fast that we *see* the steam immediately after it escapes, so that the difference between the times of seeing it and hearing the whistle is the time that it has taken the sound to travel from the whistle to us.

The velocity of sound through the air has been very carefully measured. It is found to vary according to the temperature. When the temperature of air is at the freezing-point of water, 32 degrees in our common thermometers (Fahrenheit's), sound travels through it 1090 feet per second. And its speed is about 1 foot more per second for every degree that the thermometer is above 32°.

How fast does sound travel through the air when the temperature is 70° ?

206. Solids and Liquids may also convey Sound.

Experiment 56.—Get a companion to scratch one end of a long piece of wood (a board in the floor or a sound fence-rail will do) lightly with a pin. By putting your ear to the other end you can hear the scratch distinctly, although you cannot hear it through the air when you lift your ear from the wood. Try the same thing with a long bar of iron.

Experiment 57.—Get a companion to strike two stones together 10 feet from you, and notice how loud it sounds. Hold your head, or one ear, under water while he strikes the stones together under the water, at the same distance, and notice how much louder it sounds.

FIG. 116.—STETHOSCOPE.

Sound travels faster and farther through solids and liquids than through the air. Through iron it travels about 16,000 feet per second, through most kinds of wood almost as fast, and through water about 5000 feet per second. The *stethoscope* is a small tube of wood or metal widening out at one end, which is much used by physicians. The physician places the wide end upon

his patient's chest, and puts his ear to the other end. The faint sounds made by the organs in the chest are distinctly carried to his ear through the stethoscope, and he can judge of their condition. The Indians are said to put their ears to the ground and thus hear the approach of their enemies long before it could be heard through the air.

The ordinary *string telephone* which boys make by knocking the bottoms out of two fruit-cans, stretching parchment tightly over one end of each, and joining these parchments with a stretched string, will convey sound quite a distance. A whisper in one can easily be heard in the other across the street. And when carefully made and very fine copper wire is used instead of string, conversation can be carried on through them for a quarter of a mile or farther.

Experiment 58.—Suspend a poker by two strings, and thrust the fingers holding the poker into your ears. Then swing the poker against a piece of wood, and you will be surprised at the sound.

207. **Loudness of Sound.**—Tap a table gently, and a faint sound is produced; strike it hard, and a loud sound is produced; or, better, pull a violin-string a very little to one side, and it sounds faintly; pull it strongly to one side, and it sounds loud. *Short vibrations of the sounding body produce faint sounds, long vibrations produce loud ones.* Short vibrations of the sounding body make short vibrations of the particles of air, and longer vibrations of the body make longer vibrations of the particles of air. Hence although each particle of air in a sound-wave moves only a very short distance forward and backward, yet it makes a longer swing when conveying a *loud* sound than when conveying a *faint* one.

208. **Loudness of Sound affected by Distance.**—Common experience teaches us that all sounds grow fainter as they get farther from the sounding body, and finally become too faint to be heard. But if, instead of being allowed to spread in every direction, the sound be confined to a narrow tube, it is carried much farther. Hence *speaking-tubes* are often found in large buildings so arranged that a whisper into one end of the tube can be heard at the other end in the farthest corner of the building. *Speaking-trumpets* are much used at sea to enable the voice of the officer in command

to be heard better and farther in any one direction. They seem to guide the sound of the voice in one direction, so

FIG. 117.—SPEAKING-TRUMPET.

that it is louder and goes farther than if allowed to spread. *Ear-trumpets* are funnel-shaped instruments that collect all the sound that enters the mouth of the funnel and concentrate it into a small opening at the other end of the ear-trumpet. By putting the small end to the ear, partially deaf persons can hear better.

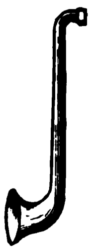


FIG. 118.—EAR-TRUMPET.

If sound moves through the air unobstructed in all directions, and if the air is uniform, or homogeneous, *the loudness must vary inversely as the square of the distance from the sounding body*. Twice as far off the sound would be one-fourth as loud, three times as far off one-ninth as loud, etc. This is because at twice the distance from the sounding body the air in a hollow shell or surface of a sphere of *twice* the former radius is vibrating. But surfaces of spheres increase according to the *squares* of the radii; therefore the sound is spread out over *four* times as much surface, and must be one-fourth as loud at any one place.

209. **Conditions of the Atmosphere as affecting Sound.**—Although sound travels many times faster than the strongest wind, yet it can often be heard three or four times as far with the wind as against it. The cause is not certainly known.

It was formerly thought that rain, snow, fog, etc., obstructed sound; but Tyndall has recently shown that they have no effect whatever upon the transmission of sound. The same observer has shown the existence of *acoustic clouds* in the atmosphere. These are masses of air differing from the surrounding air in *temperature*, or in the *amount of*

moisture they contain. They have no connection with ordinary clouds, they are entirely invisible, and the air may be full of them upon the clearest day. Yet they obstruct and reflect sound very much. It is to the reflections from these acoustic clouds that the rolling of thunder seems to be mainly due. And probably the fact that noises are heard farther and more distinctly by night than by day is partly due to there being fewer acoustic clouds formed by night than by day, and partly also to the stillness of the night.[1]

210. **Reflection of Sound.**—When sound-waves strike a wall or other obstruction, they rebound or are reflected, and the angle of reflection is equal to the angle of incidence.

Fig. 119 illustrates an experiment in the reflection of sound. Two concave metal mirrors are placed facing each other and so far apart that the ticking of a watch could not be heard from one to the other. Then, as shown in the figure, a watch is hung in front of one so that the sound-vibrations are reflected out from the mirror in a straight line to the other one, which concentrates them so that if the ear is placed there, or if a short speaking-tube runs from there to the ear, the ticking of the watch can be distinctly heard.

211. **Whispering-Galleries.**—In some large circular buildings it is found that low whispers spoken near the wall on one side of the building can be heard distinctly at the opposite side. The sound seems to be reflected repeatedly until it reaches the opposite side, when it is so concentrated from all directions that it is distinctly heard. The gallery in the dome of St. Paul's Cathedral in London is a famous whispering-gallery. The dome in the Capitol at Washington is another.

212. **Echoes.**—When the reflecting surface is near the source of the sound, as the walls of an ordinary room in

[1] The writer's own observations leave no doubt in his mind that the popular notion that distant sounds can be heard more distinctly before a storm is correct. Probably at such a time the air is homogeneous and free from these acoustic clouds; but some instances are not easily explained in this way.

which a sound is made, the reflection follows the sound itself so closely that it cannot be distinguished from it. It

FIG. 119.—CONCENTRATION OF REFLECTED SOUND.

may, however, modify one's voice in some way and give a peculiar *resonance* to the room. But when the reflecting

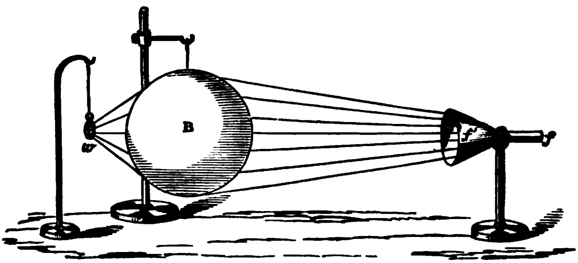


FIG. 120.—REFRACTION OF SOUND.

surface is fifty feet or more away, the reflection can be heard after the sound ceases, and is called an *echo*.

Between two walls, or between cliffs, and in like places, echoes are often repeated many times by being reflected from side to side. Large halls sometimes have an echo that is very annoying to both the speaker and his hearers. In such cases the echo is generally less when the hall is filled with people, and especially so if the seats rise towards the back of the hall, or if there is a gallery there.

213. **Refraction of Sound.**—Fig. 120 shows how a faint sound may be concentrated so as to be heard farther off than it could otherwise be heard. *B* is a small balloon filled with some gas *heavier* than air, as carbonic acid. The waves of sound are bent around, or refracted, by the heavy gas and concentrated at one point. If the ear is placed there, or if a funnel is placed there to convey the sound to the ear, the ticking of the watch may be distinctly heard. This refraction of sound is like the concentration of the sun's heat with a burning-glass. In light it is a very important subject, and will be fully taken up there.

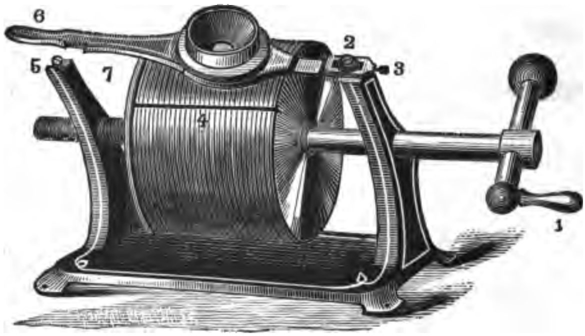


FIG. 121.—EDISON'S PHONOGRAPH.

214. **The Phonograph.**—Fig. 121 represents a *phonograph*, a remarkable talking-machine recently invented by Mr. Edison.[1] 4 is a brass cylinder into which is cut a continuous groove, winding around it from one end to the other. When the handle 1 is turned, the screw-thread, seen under 7, moves the cylinder slowly along to the left

[1] Thomas A. Edison (1847–), a famous American inventor, who lives at Menlo Park, New Jersey.

while it is revolving. Above 4 is the mouth-piece, the bottom of which is covered with a thin elastic metal plate. From the under side of this plate a short needle runs down. To use the phonograph, a piece of tin-foil is wrapped tightly around the brass cylinder, and the handle 6 is pushed down upon the screw-head 5 and held there. This presses the needle down upon the tin-foil. If the handle is turned as the cylinder revolves and moves to the left at the same time, the needle pushes the tin-foil down into the groove beneath it, and thus makes a shallow spiral groove in the tin-foil. But if you talk into the mouth-piece the sound-waves will make the elastic plate vibrate, and the needle, being attached to it, will also vibrate up and down, and will make successive dots and dashes in the bottom of the groove in the tin-foil. If we were to take the tin-foil off the cylinder and examine the bottom of the groove with a microscope, we should find a peculiar indentation for every pulse of the sound-wave. But, instead of taking the foil off the cylinder, let us raise 6 and run the cylinder back to the starting-place. If the needle be now pressed down into the groove and the handle be turned as it was when we were talking to it, the indentations there will cause the needle to vibrate up and down, precisely as it vibrated when it caused these indentations, and the needle will vibrate the plate, just as the plate at first vibrated the needle, and hence cause it to send out into the air the same vibrations or sounds as were driven against it when you talked to it. In this way the phonograph repeats the words said to it, as well as laughter, crying, and sounds of any kind. But, as its voice is feebler than yours, it needs for a speaking-trumpet a cone of paper, in order that it may be heard over a large room.

SECTION II.—MUSICAL SOUND.

215. Noise and Musical Sound.—When the sound-vibrations are irregular, no two at the same distance apart, we hear a *noise*, such as would be made by the crash of a pane of glass. But if the waves of sound follow one another at regular intervals, we hear a *musical sound*, such as is made by the prong of a tuning-fork or a violin-string, which vibrates regularly, and produces sound-waves all at the same distance apart. No matter how the vibrations are caused, if they are at regular intervals and rapid enough, they will produce a musical sound. Taps on a table, the striking of a stick upon the pales of a fence or the teeth of a wheel,

the puffs of a locomotive, if regular and rapid enough to blend together, produce a sound as truly musical as the voice of the best singer, or a note of a flute, though it may *not* be as pleasant.

If a number of boys should run across a room all keeping step, the noise of their steps would be heard at regular intervals; and if they could run so fast that the sounds from their steps would blend into one continuous sound, they would make a *musical note*. But if the same boys were to run back just as fast without keeping step, their steps would make a *noise*.

216. **Pitch of Sounds.**—Experiment 59.—Run the back of a knife over the milled edge[1] of a coin. You will produce a musical sound. Run the knife over the edge *faster*, and your sound will be higher; run it still faster, and the pitch will be still higher.

Experiment 60.—Wind a string around the axis of the wheel (Fig. 122), and pull it so as to revolve the wheel rapidly. Hold a card to the teeth, and a musical sound is produced. Revolve the wheel faster and faster, the pitch becomes higher and higher.

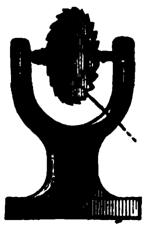


Fig. 122.

These experiments show that *the pitch of sounds depends upon the rapidity of the vibrations.* Their *loudness* depends, as has been said, upon the extent of the vibration of the sounding body, and, therefore, of the particles of air; their *character*, such as distinguishes the sound of a violin from that of a piano or a human voice, is due to other causes; but the *pitch* of sounds is due solely to the number of vibrations per second.

217. **The Siren.**—The number of vibrations which produce any given pitch of sound is best found by means of a piece of apparatus called a siren, which makes a musical sound by a succession of puffs of air following one another

[1] If you notice, you will see that all the gold and silver coins now made in the United States have their edges finely notched. They are said to be *milled*. Perhaps you can think or find out why they are so made.

very quickly. Fig. 124 shows a siren cut open, so that its mechanism may be understood. Air is forced up through the tube below from a pair of bellows (not shown in the figure) into the air-chamber seen open. Leading up from this is a small opening, and above is a wheel made to revolve, and having a circle of holes in it. When one of the holes in the wheel comes over the hole in the top of the air-chamber, the air forced in by the bellows can puff out;

FIG. 123.—THE SIREN.

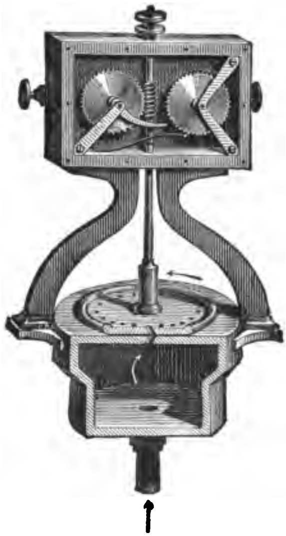


FIG. 124.—THE SIREN,—INSIDE VIEW.

when the solid part of the wheel is there, it cannot. So, as the wheel turns, a succession of puffs is heard as the holes in the wheel pass, one after another, over the hole leading up from the air-chamber. If the wheel turns fast enough, the separate puffs cannot be distinguished from one another, but are blended into one sound, rising higher in pitch as the wheel goes faster and therefore produces more puffs per second. By means of the cog-wheels seen at the top of the figure the wheel registers its revolutions, and the

hands on the dials (Fig. 123) show how many revolutions the wheel makes per second. This multiplied by the number of holes in the wheel gives the number of *puffs*, and therefore the number of sound-waves or vibrations, per second. It will be noticed in Fig. 124 that the opening[1] leading upward from the air-chamber slants. This forces the air obliquely against the wheel and causes it to revolve.

This ingenious little instrument will produce a note of any pitch, from the lowest to the highest, and tell us the number of vibrations it makes to produce it. And if a note be sounded on any musical instrument, the pitch of the siren may be raised (by working the bellows harder) until our ears tell us that its pitch is the same as that of the musical instrument; then the number of vibrations per second of the siren is the number that the instrument is making. In this way we can count the vibrations which the human voice, or any other musical sound of any pitch, is producing.

218. **The Limits of Human Hearing.**—It is found that when the puffs of the siren are fewer than 16 per second they are heard as separate puffs, but when they reach about that number they cannot be separately heard, and make a continuous and very low note. The lower limit of sounds, then, is about 16 vibrations per second, which make a sound of the lowest possible pitch. When the puffs reach about 38,000 per second their exceedingly shrill piercing note suddenly ceases, and though the wheel can be *seen* to be revolving, and, as the hands show, faster than ever, nothing can be heard. We have reached the *upper* limit of human hearing. The ear can hear nothing when the vibrations are more than about 38,000 per second.

[1] There is really a *circle* of holes in the top of the air-chamber, corresponding exactly with the holes in the wheel, and when the air puffs through one hole it *puffs* through all. Only one puff is heard, but it is stronger, and the wheel can be driven around much faster, than if there were but one upward opening.

The pitch of the keys of our ordinary pianos ranges from 27 to 3482 vibrations[1] per second, while the middle C-string vibrates[1] 272 times per second. Human voices from the deepest bass of men to the highest treble of women lie between 80 and 1000 vibrations per second.

The upper limit of hearing varies in different persons, and very curious results often follow from this. "Nothing can be more surprising," says Sir John Herschel,[2] "than to see two persons, neither of them deaf, the one complaining of the penetrating shrillness of a sound, while the other maintains there is no sound at all." And Tyndall notes that in crossing the Alps with a friend, "the grass at each side of the path swarmed with insects, which to me rent the air with their shrill chirruping. My friend heard nothing of this, the insect-music lying beyond his limit of audition."

219. **Lengths of Sound-Waves.**—If the temperature of the air is 62°, sound travels through it about 1120 feet per second. And if a tuning-fork that vibrates 256 times per second is sounded, at the end of 1 second the first wave of sound must be 1120 feet from the fork, and the 256th has just left the fork, and so scattered through the 1120 feet there are 256 waves. As the tuning-fork gives out a *musical sound*, the waves must be at equal distances from one another, and, therefore, dividing 1120 feet by 256 gives us the distance between any two successive condensations, or the length of a wave. It is 4 feet 4⅜ inches.

When the temperature of the air is 82°, a man is speaking in a pitch that produces 120 vibrations per second: what is the length of one of the sound-waves? *Ans.* 9⅓ feet.

At the same temperature a woman's voice is producing 300 vibrations per second: what is the length of one of the sound-waves that she produces?

SECTION III.—MUSICAL INSTRUMENTS.

220. **The Sonometer.**—The piece of apparatus most commonly used in experimenting with musical sounds is the

[1] The vibrations meant here and elsewhere are from one side of the swing across to the other, and *back again*, sometimes called *double vibrations.*

[2] A famous English astronomer and scientist, born 1792, died 1871, son of the great astronomer Sir William Herschel.

sonometer. It is a long wooden box, over which one or more wires are stretched by weights. The wire rests on wooden bridges at the ends of the box, and between them is a bridge which can be moved anywhere along the scale

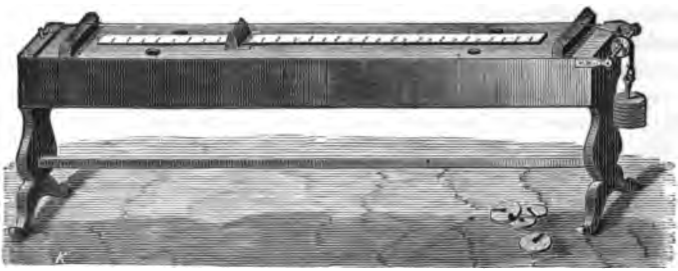


FIG. 125.—SONOMETER.

of inches which is marked off under the wire. If the stretched wire be pulled aside with the thumb and finger, or if it be bowed with a violin-bow, a clear musical sound will be produced that lasts a short time.

221. **The Laws of Vibrating Strings.** — If the wire be shortened, by moving the movable bridge, so that *half* of it vibrates, it is found to make *twice* as many vibrations per second as the whole wire. If *one-third* of it is vibrated, it will vibrate *three* times as fast as the whole; if *one-fourth, four* times as fast,[1] etc. Hence,

222. **The First Law.**—*The number of vibrations of a string is inversely proportional to its length.*

Without using the movable bridge, put more weights on the string until they are *four* times as heavy as at first, the string will vibrate *twice* as fast as at first; with *nine* times as much weight it will vibrate *three* times as fast, etc. Hence,

[1] The number of vibrations can be counted by bringing the siren to the same pitch and counting its vibrations; or any one even slightly acquainted with music can tell the relative number of vibrations by the pitch, as will be explained in the next section.

223. **The Second Law.**—*The number of vibrations of a string is directly proportional to the square root of its tension.*

If a second wire of the same material, but weighing *four* times as much to the yard, be stretched beside the first one, and the stretching-weights and the lengths are the same, it will vibrate *one-half* as fast; one *nine* times as heavy will vibrate *one-third* as fast, etc. Hence,

224. **The Third Law.**—*The number of vibrations of a string is inversely proportional to the square root of its weight.*

The Pitch of Vibrating Strings.—As the pitch of musical sound depends solely upon the number of vibrations per second, the laws of vibration are also the laws of pitch.

Experiment 61.—Vary the length of the wire, the stretching-weight, and the weight of the wire on the sonometer, and notice the changes in pitch.

Experiment 62.—Lift the lid of a piano, sound the highest key, and notice that the *shortest* wire[1] is struck. Strike the lowest key, the *longest* wire is struck: which law? Repeat the law to yourself. Notice also that the wires struck by the higher keys are very *thin* and *light*, while those struck by the lower keys are much *heavier* and have extra wire wrapped around them to make them heavier still: why? Repeat the law.

If you cannot play the violin yourself, watch some one tuning and playing one. Why are some of the strings heavier than others? Which have the highest pitch? What is peculiar about the one that has the lowest pitch?

What effect does it have upon the pitch to tighten up the strings in tuning the instrument? Repeat the law.

Why does the player touch the strings in different places while playing? Explain this fully by referring to the law.

225. **Sympathetic Vibrations.**—**Experiment 64.**—Sound a tuning-fork, and set the end of the handle on a table or against the panel of a door. It sounds very much louder than in the air. The vibrations of the fork have set the wood to vibrating too, and it sounds out louder than the fork.

The vibrations of the wood thus caused are called *sympathetic vibrations.* They are very commonly produced, and are of great importance in music and sounds generally.

[1] In most pianos there are two wires for each key, both, of course, of the same length. In some of the better modern pianos there are three for each key.

For experimentation, tuning-forks are very frequently mounted upon sounding-boxes (Fig. 126), which strengthen the sound as the table did. It is not necessary that the sounding body actually touch another to set it to vibrating. It may be done by the sound-waves in the air.

FIG. 126.—TUNING-FORK ON SOUNDING-BOX.

Experiment 64.—Raise the lid of a piano, lift the dampers from the wires by putting your foot on the right pedal, and make a sound over the strings with the voice. The sound-waves set in motion by your voice cause the sounding parts of the piano to vibrate, and when your voice stops you hear the piano sounding *in exactly the same pitch as your voice had.*

Experiment 65.—If two tuning-forks *of the same pitch*, mounted on sounding-boxes, be placed side by side, and one of them be sounded, the other will take up the sound, and may be heard after the first is silenced. But if the pitch of one of them be lowered by sticking a small lump of wax upon one of its prongs, the sounding of the other will not set this one to vibrating.

The strings of a violin would give out very feeble sounds if they were not reinforced by the sympathetic vibrations of the wooden shell below them. Underneath the strings of a piano you may see a thin board,—the sounding-board. Without that the sound of the piano would be insignificant.

Experiment 66.—Touch the handle of a vibrating tuning-fork to the body of a violin or to the sounding-board of a piano, and notice how it sounds out. It will keep on sounding after you have taken away and silenced your fork. Do not fail to notice that it gives out the same pitch as the fork.

Experiment 67.—Stretch your sonometer wire, or one like it, across an open door-way, and notice the comparative feebleness of the sound. You see why you have a wooden box under your wire.

Professor Tyndall illustrated this, as well as the conduction of sound by solids, very beautifully in his lectures in London. On the second floor below his lecture-room he placed a piano. A pine rod rested on the sounding-board of the piano and came up through the floors in front of his desk. When the piano was played, the rod was of course set in vibration, but too feebly to be heard. When, how-

ever, Professor Tyndall laid a violin on the end of the rod, the vibrations of the rod set the wood of the violin to vibrating, and it reproduced the music of the piano so that it could be heard all over the room. A guitar, a harp, and even a thin flat board, when put in the place of the violin, reproduced every note of the piano.

226. **Resonance.**—This capability of being set to vibrating by sound-waves and of giving forth sound of the same pitch is called *resonance.* Different bodies possess it in various degrees according to their material and their shape.

Experiment 68.—Sound the tuning-fork and touch the end of the handle against your slate; a window-pane; a book, open and shut; a stone or brick wall; a lath-and-plaster partition; iron; stone; the blackboard-pointer; your hand, etc. Notice the differences in intensity, and whether they are due to the material or the shape of the body.

Resonance may also be caused by sympathetic vibrations of a body of air, and it is to such vibrations that the term is usually applied.

Experiment 69.—Fix the mouth as if about to say *e*, and bring a sounding tuning-fork close before it. Quickly change the mouth as if to say *o*, and notice that the sound is strengthened. The latter shape gave a more resonant body of air, hence the stronger sound.

Experiment 70.—(Fig. 127.) Take a deep glass jar and hold the sounding tuning-fork over its mouth. The sound of the fork will probably be only slightly strengthened. Pour water into the jar quietly; the resonance increases as the air-column shortens, until presently it becomes very strong. We have found the length of air-column which is best vibrated by the waves from our fork. If more water be poured in, the resonance decreases again.

Let us see if we cannot learn why one particular length of the air-column makes the resonance greatest. Fig. 128 represents the fork vibrating over the jar. As the prong moves from its position of rest down to *b*, the air is condensed below it, and the condensation moves down to the bottom of the jar (or to the surface of the water) and is reflected back again. In order that the vibrations of the air should fit those of the fork, the column of air ought to be long enough to allow this condensation (after reflection) to reach the prong again just as the prong reaches the middle of the vibration; or while the prong is making an excursion to one side and back to the middle again, which is half a vibration, the condensation must travel twice the length of the air-column. In swinging up from its middle position the prong produces a *rarefaction,* which must also travel to the bottom of the column and back again while the prong is making the

upper half of its vibration. It is clear that if the vibrations of the air-column did not thus fit those of the fork, they would interfere with one another or with the fork, and thus be weakened. When the vibrations of two bodies fit together, as do those of the fork and the column of air when the resonance is greatest, they are said to be *synchronous*.[1] Since a pulse must pass along the air-column *four times* during one complete vibration of the fork, the tube ought to be one-fourth the length of a sound-wave of that pitch. If the depth of the air-column which sounds loudest for a fork vibrating 256 times per second be measured, it will be found to be about 13 inches deep,

Fig. 127.

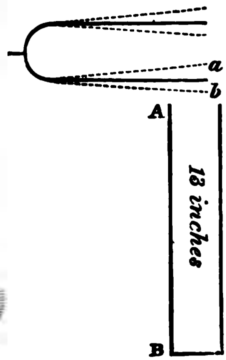


Fig. 128.

and we have found in Art. 219 that a fork making 256 vibrations per second sends out waves 52½ inches long, which very accurately confirms our reasoning.

Fig. 129 represents a piece of apparatus often used to illustrate resonance. It consists of a bell, best sounded by drawing a violin-bow across its edge, and beside it a tube with a movable bottom that has been adjusted to the right depth for the bell. While the tube is

[1] Pronounced sink′rŏ-nus; derived from the Greek, and meaning *happening at the same time*, or *simultaneous*.

at some distance from the bell the latter sounds feeble, but when we slide the tube up close to it the bell sounds surprisingly strong. Move the tube back and forth, and notice the changes.

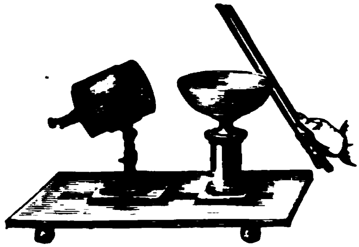


FIG. 129.

The murmuring sound heard in a hollow shell when placed close to the ear is due to resonance. Tyndall says, "Children think they hear in it the sound of the sea. The noise is really due to the reinforcement of the feeble sounds with which even the stillest air is pervaded, and also in part to the noise produced by the pressure of the shell against the ear itself."

Questions.—When the air has a temperature of 62°, what is the length of the tube that will resound best to a fork vibrating 480 times per second? *Ans.* 7 inches. What to one vibrating 280 times per second?

Sound travels nearly four times as fast in hydrogen as in air. Would a column of hydrogen have to be longer or shorter than a column of air to be synchronous with a certain tuning-fork?

227. The Two Classes of Musical Instruments.—Most of the musical instruments are either stringed instruments or wind instruments. The piano and violin are the most common stringed instruments. The music of all of this class of instruments is made by the vibrations of strings, generally reinforced by the sympathetic vibrations of sounding-boards. In wind instruments tubes full of air are in some way set to vibrating, and these bodies of air give out the sounds. Pipe- and cabinet-organs, flutes, horns of all kinds, are wind instruments.

228. Interference of Sound.—We have learned (Art. 159) that in water-waves, when the highest part of one wave meets the lowest part of another of the same size, the two waves neutralize each other and produce smooth water. In the same way, when the condensed part of one sound-wave meets the rarefied part of another, silence is produced.

Experiment 71.—Sound a tuning-fork, hold it upright a short distance from the ear, and roll it slowly around between the thumb and the finger. Its sound will grow fainter, almost or entirely die out, then grow strong again, and so on as it continues sounding.

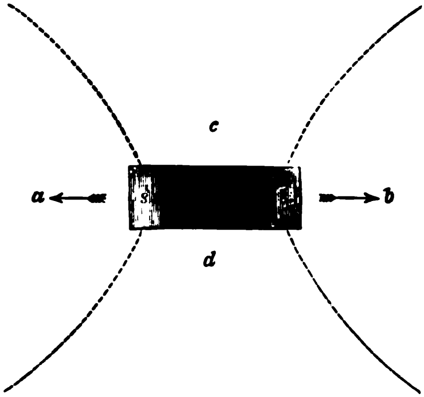


Fig. 130.—Interference of Sound, shown with a Tuning-Fork.

Fig. 130, which represents the ends of the fork, will help to make the cause of this clear. When the prongs are moving outward, there are condensations at *a* and *b*. But, as the air will rush in from the sides to fill the partial vacuum caused by the prongs, there will be rarefactions at *c* and *d*. Along the dotted lines the condensations and rarefactions meet and destroy one another. These are the lines of silence. When the prongs move back again, they will drive the air out at the sides and cause condensations at *c* and *d*, while at *a* and *b* there will be rarefactions, and there will be the same interference along the dotted lines as before.

Fig. 131.

In the experiment just described, the fork must be held close to the ear; but by reinforcing the sound of the fork with a resonating-jar it may be heard all over a room. If the vibrating fork be slowly rotated as it is held over the jar, the alternations of loud sounds and silence will be very striking. If the fork be held in the position of silence, and a pasteboard tube be slipped over one prong, as shown in Fig. 131, the

sound will swell out as loud as ever. The vibrations of the uncovered prong are protected from the vibrations of the other, and are no longer quenched.

229. **How the Vibrations of the Air-Columns are excited in Wind-Instruments.**—Fig. 132 shows a complete and a sectional view of an organ-pipe from a pipe-organ or large church-organ. The air is forced up from below by a bellows, and, rushing against the sharp edge of an opening in the pipe, is thrown into vibrations, which communicate themselves to the column of air in the pipe. It is much like an ordinary willow whistle. In a cabinet-organ the air is set in motion by the vibration of *reeds*. A reed is a strip of brass, fastened only at one end, and arranged so as to vibrate in an opening which it almost fills. There is a reed of a different pitch for every key, and pressing down that key opens the way for the air to pass from the bellows to its reed. The reed is made to vibrate by forcing air from a bellows through the opening around the reed. The vibration of the reed sets the air about it in motion. The melodeon, which has been almost superseded by the cabinet-organ, also produces its music by reeds of this kind, and in a very similar way. (Fig. 133.) The accordion is almost literally a hand cabinet-organ, with bellows and reeds. The common mouth-organ is a reed instrument, and its reeds can easily be seen.

FIG. 132.—ORGAN-PIPES.

Experiment 72.—Take a piece of wheat- or rye-straw, and slit a tongue in it down to a joint, as shown in Fig. 134. This tongue is a reed, and the whole is a simple reed instrument. Blow into the open

end, and note the pitch. Cut an inch or two off the open end and blow again; the pitch is higher. Cut off another piece; the pitch is

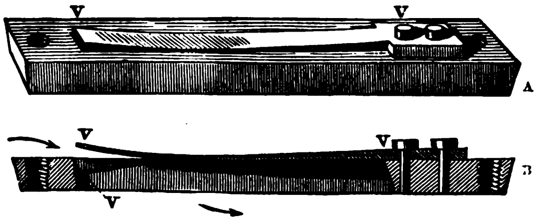


FIG. 133.—CABINET-ORGAN REEDS.

still higher. Careful experiments show that, so far as length is concerned, the law of the sound-vibrations of a column of air is the same as those of a string: *the number of vibrations of a column of air is inversely proportional to its length.*

FIG. 134.—REED MADE OF WHEAT-STRAW.

The clarionet has a wooden reed in the mouth-piece.

The flute and the fife are played by blowing against the sharp edge of an opening in the side of the tube. The vibrations are caused very much in the same way as in the pipe-organ, and in the same way as when one whistles in a key.

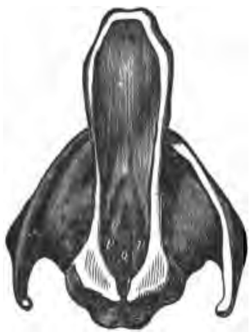


FIG. 135.—THE VOCAL CORDS.

In a cornet or a horn the lips of the player, pressed against the mouth-piece, act as reeds.

230. **The Human Voice.**—The voice is produced in the upper part of the windpipe: the "Adam's apple" marks the place. Fig. 135 shows the vocal apparatus as looked down upon by means of a laryngoscope.[1] *o* is a slit through

[1] Pronounced la-ring′go-skōp. A pair of mirrors so arranged as to show this part of the throat.

which the air passes to and from the lungs. On either side of this is a membrane, *v*, *v*, projecting from the sides of the windpipe. These membranes are called the *vocal cords*, although they are not cords at all. In ordinary breathing these cords are loose and close to the sides of the windpipe, leaving a wide opening between them. But when we wish to make sounds, they are, by muscular action, stretched tight and brought close together, so as to leave only a narrow slit between them. The air from the lungs passing between them sets them in vibration, and their vibrations produce the sounds of the voice, just as the reeds of a cabinet-organ produce sound. *The human voice is a reed wind-instrument.*

The vocal cords can only make sounds of different pitch and loudness. The resonance of the cavity of the mouth and nose, varying with its shape, changes the sounds of the vocal cords into the distinct vowels and consonants. The pitch of one's voice depends upon the length and thickness of the vocal cords. The ordinary tones of women's voices produce more than twice as many vibrations per second as those of men's voices (Art. 218).

Experiment 73.—Notice that women or girls, and boys whose voices have not changed, show no Adam's apple in the neck, but that it is prominent in men, and especially in men with bass voices: why is this?

Experiment 74.—Get from a butcher the upper part of the windpipe of a hog or other slaughtered animal, cut it open from front to back, and examine the vocal cords. They are very much like yours. You will see what will look like *two* pairs of cords. The lower ones are the true vocal cords; the upper ones perhaps serve to modify the sounds which the lower ones alone produce.

231. **Vibrations of Strings in Parts.**—**Experiment 75.**—Touch the middle of the sonometer wire with your finger, or with a feather, and draw the bow across the middle of *one half*. The middle point which was held by the feather is stationary, but each half of the wire is vibrating. Set a rider, made by folding a bit of paper into the shape of a V, upon the middle of either half, it is thrown off. Set it upon the middle of the wire, it stays there: why?

Experiment 76.—Again, touch the wire at one-third the distance from one end, and draw the bow across the middle of *one third*. The wire will vibrate in thirds. Test the points of greatest vibration and of no vibration with the riders. In the same way the wire may be made to vibrate in fourths, fifths, etc.

The parts of the wire which we have made to vibrate are called *segments*. The points between the segments, where there was no motion, are the *nodes*. When a string is thus vibrating in parts only, its pitch is higher than if

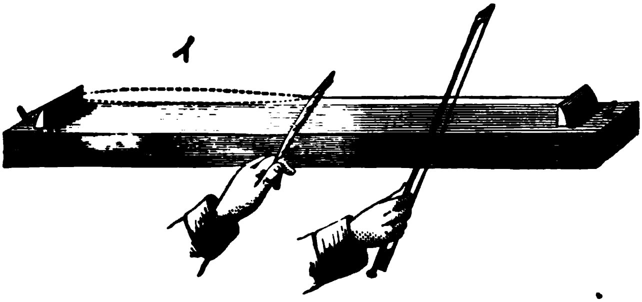


FIG. 136.—STRING VIBRATING IN HALVES.

it were vibrating as a whole, for, according to the first law of vibrating strings, when it vibrates in halves each segment vibrates twice as fast as the whole string would; when in thirds, each segment vibrates three times as fast, etc. When a string vibrates in parts, the segments are always

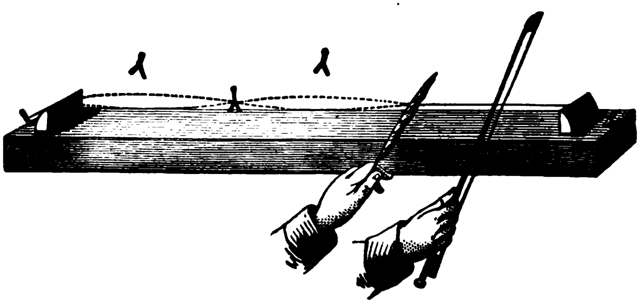


FIG. 137.—STRING VIBRATING IN THIRDS.

equal; each is an exact division of the whole string. And again, when a string vibrates in parts, *any two consecutive parts are always moving in opposite directions.* Thus, in Fig. 136, while one half moves up the other half is coming down;

and in Fig. 137 the two end segments are swinging in one direction while the middle one swings in the other.

232. **A String may vibrate in Parts and as a Whole at the Same Time.**—If the wire of the sonometer be plucked near one end, it will vibrate in parts and as a whole at the same time. Fig. 138 shows a string thus vibrating as a

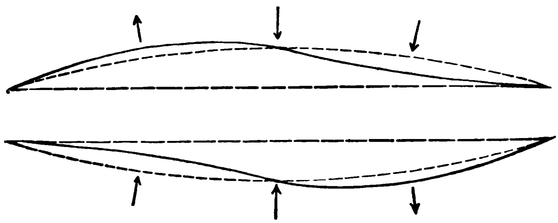


FIG. 138.—STRING VIBRATING AS A WHOLE AND IN HALVES.

whole and in halves. The middle arrows show the direction of the whole string, the others show the smaller and quicker vibrations of the halves. In the same way it may, while vibrating as a whole, be also vibrating in thirds, fourths, etc. And it may even be vibrating as a whole, in halves, thirds, fourths, etc., *all at the same time.*

233. **Vibrations of Air-Columns in Parts.**—The air in an organ or other pipe may vibrate as a whole or in parts, or as a whole *and* in parts at the same time, just as a string may.

Experiment 77.—Take a tube of glass or other material, about 18 inches long and from a quarter to half an inch in diameter, close one end with the finger, and blow rather gently across the other, and you hear a low note, the lowest or the *fundamental* note of your tube: the air-column is vibrating as a whole. Blow again and strongly, and you make a much higher note. The air-column is vibrating in segments. Try the same experiments with the lower end of the tube open: the results are like the others.

In trying the above experiment you must have noticed that the lowest note of the open pipe was much higher than the lowest note of the closed pipe. This is because the air in a pipe open at both ends can never vibrate as a whole: there is no bottom to the pipe to

send the wave back again. The lowest note that such a pipe can give is when it is vibrating in halves; then the two waves meet each other at the middle and turn each other back. Just at the middle there is no motion of the particles: there is a node there. A pipe open at both ends gives the same pitch as one of half its length which is closed at one end. In fact, it is just the same as two closed pipes with the closed ends together. The keys in horns and the finger-holes in flutes, etc., enable the player to change the nodes and the lengths of the vibrating columns of air, and therefore to vary the pitch of his tones.

234. **Overtones.**—When a whole string, or a column of air, and its various parts are vibrating together, the vibrating parts also produce tones, higher in pitch, of course, than that of the whole string. These are called *overtones*. The overtones cannot usually be distinguished from the fundamental tone by ordinary ears, and so they do not affect the pitch of the sound, which is that of the string as a whole; but they do change the *character* of the tone, as we shall see hereafter.

Helmholtz[1] has invented an instrument to enable us to detect the overtones in a compound sound. It is called a *resonator*, and is shown in Fig. 139. This is made of just the size to be resonant to the sound made by *halves* of a certain string. When the string is sounding as a whole, and also in halves, the small end of the resonator is put into the ear, and by its resonance it so strengthens the sound of the halves that they can be distinctly heard. Another resonator of different size will strengthen the sound of the thirds enough to be heard, another the fourths, and so on. By having a whole set of these resonators, all the overtones in a compound sound can be dis-

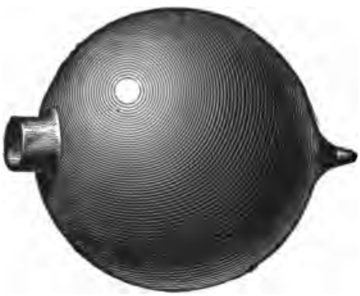


Fig. 139.—Helmholtz's Resonator.

[1] H. L. F. Helmholtz, 1821–, Professor of Physics in the University of Berlin, and one of the greatest scientists of this or any other age.

tinguished. These instruments show that the sounds of almost all our musical instruments are very complex. The strings of pianos and violins, the reeds of organs, etc., besides sounding as wholes, are also vibrating in halves, thirds, fourths, fifths, and often many more parts. The human voice has many overtones.

235. Manometric Flames.—Koenig, an instrument-maker of Paris, has devised an apparatus which shows the effects of the overtones very beautifully. It consists of two parts, one of which is shown in Fig. 140. *m* is the mouth-piece of a tube, across the other end of which is stretched a piece of india-rubber, *r*. *f* is a gas-burner, fed by the tube *g*. The gas-tube is separated from the other only by the thin sheet of rubber. The vibrations of the voice sounding at *m* set the rubber partition to vibrating, and drive out the gas in puffs. These cause changes in the height of the flame, but they are too rapid to be noticed, and the gas-flame looks to the eye to be steady. But when a square box having its four sides covered with mirrors (Fig. 141) is rapidly rotated in front of the flame, its changes can be seen.

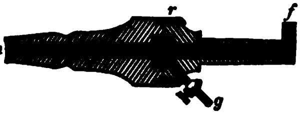


FIG. 140.

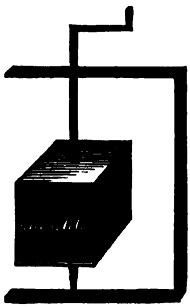


FIG. 141.

Fig. 142 shows the various forms that may be produced. 1 shows the reflection of the gas-flame when the mirror is stationary. 2 is the reflection when the mirror revolves without any sound being made in the tube. 3 is a low, simple sound, with no overtones. 4 is a higher simple sound, but with no overtones. In 5 the first overtone (in halves) is sounding with the fundamental, only every other vibration of the overtone being seen, the others are united with the fundamental. In 6 the second overtones (in thirds) are vibrating with the fundamental.[1]

Almost any sound can be analyzed with this instrument, making very interesting and curious experiments.

236. Character of Sound.—Besides pitch and loudness,

[1] 3 and 4 can be produced by singing into the tube *oo* as in pool; 5, by singing *a* in B♭ (second space below the treble clef); 6, by singing *a* in the note F. (From Mayer's *Sound*, p. 160.)

sound has another quality. A piano, a violin, and a human voice may all sound with the same pitch and the same loudness, and yet they sound very unlike; any one can tell them apart. This quality which distinguishes different

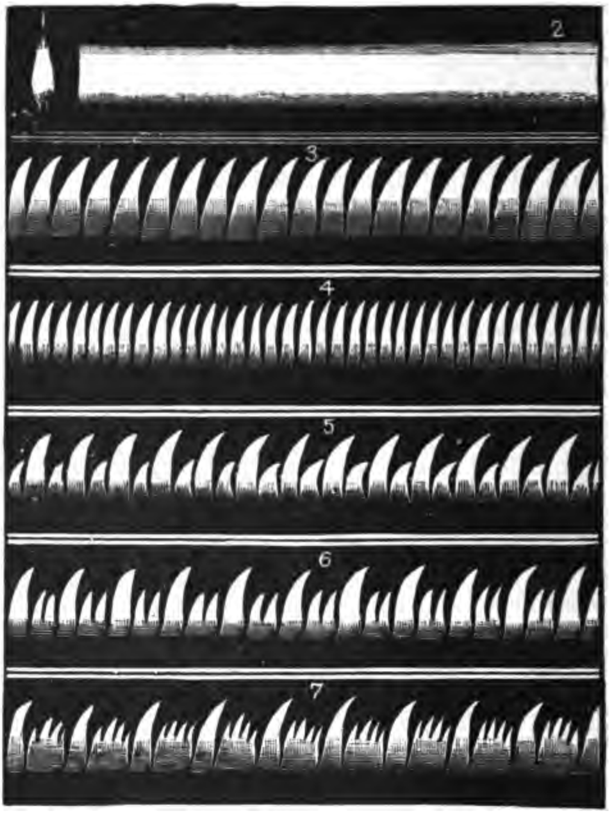


FIG. 142.—VIBRATIONS SHOWN BY MANOMETRIC FLAME APPARATUS.

kinds of sounds from one another is called *character*, or *timbre*. *The character of sounds has been found to be wholly due to the overtones.* If a sounding body is vibrating only as a whole, and not in parts, or if while vibrating as a

whole only the halves, and perhaps the thirds, are also vibrating, its sound is pure or simple. This is the case with a tuning-fork or an organ-pipe. But if a sounding body while vibrating as a whole is also vibrating in many different divisions at the same time, its sound, though of the same pitch as the other, has a very different character: it is more "brilliant." The sounds of the violin, horn, and cymbals are good examples.

237. **The Three Qualities of Sound.**—The *pitch* of sound depends wholly upon the rapidity of the vibrations. The *loudness* of sound depends wholly upon the amplitude, or length of swing, of the vibrations. The *character* of sound depends upon the number of overtones, or vibrations of parts, that are mingled with the fundamental sound. All the difference between musical sounds of any kind is made by one or more of these three qualities.

238. **Vibration of Plates in Parts.**—**Experiment 78.**—Get a piece of good window-glass about six inches square, rub its sharp edges smooth with a grindstone. Clamp it in the middle with a vise like that shown in Fig. 143, which has been fastened to the edge of a table by the lower screw. Scatter writing-sand over the glass, and draw a well-resined heavy bow across the edge near one corner, while touching the middle of another edge with the finger. The sand will arrange itself in lines as in Fig. 144. Again, touch the glass at one corner, and draw the bow across the middle of one edge, Fig. 145 will be produced.

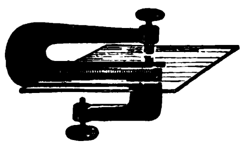


FIG. 143.

These are called *Chladni's*[1] *Figures.* The finger holds the glass still where it touches it, and starts a *node* there. The glass vibrates in parts, and shakes the sand gradually to the nodal lines between the vibrating parts where there is no vibration. As with strings and columns of air, any two consecutive segments are always vibrating in opposite directions. Fig. 146 shows some of the many sand-figures

[1] E. F. F. Chladni (klăd′ne), 1756–1827,—a German natural philosopher.

that have been thus produced by touching and bowing the plate in different ways.

Bells, gongs, cymbals, etc., vibrate in parts as these plates

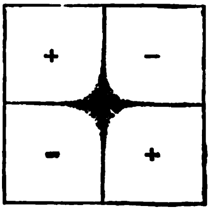


FIG. 144.

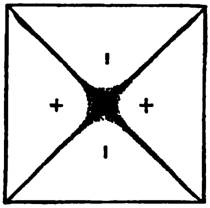


FIG. 145.

do, and both their fundamental tones and their overtones are due to such vibrations.

SECTION IV.—MUSIC.

239. **The Scale.**—There is a regular succession of eight sounds of increasing pitch used by all persons in singing or playing any musical instrument, called the *scale*. The names of these sounds as they are used in singing are *do, re, mi, fa, sol, la, si, do.*[1] In *instrumental music* the sounds of the scale are denoted by the following letters: C, D, E, F, G, A, B, C. The first or lower *do*, or C, is called the *key-note*, or *fundamental* note, of the scale.

Almost all who study this book are familiar with the scale, and can sing it for themselves. If any cannot, they may hear it by striking eight successive white keys of a piano or organ, beginning with C.

240. **The Derivation of the Scale.**—To derive the scale, let us use our sonometer again. It will be convenient to have the wire 30 inches long to start with. If it is longer than that, we may use that much of it by putting a bridge under it, 30 inches from one end.

To produce *do*, sound the whole string.

[1] Pronounced dō, rā, mē, fah, sōl, lah, sē, dō.

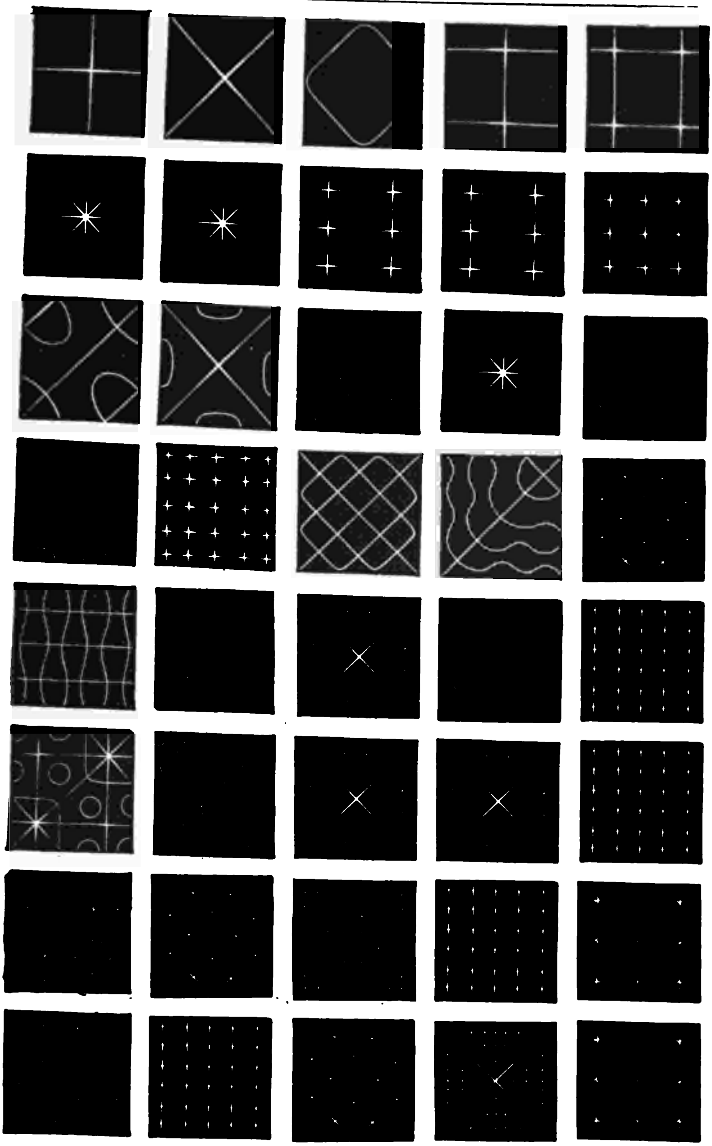


FIG. 146.—SAND-FIGURES.

To produce *re*, move the bridge so as to make the wire $\frac{8}{9}$ *as long as at first* ($26\frac{2}{3}$ inches), and sound it.

To produce *mi*, move the bridge so as to make the wire $\frac{4}{5}$ *as long as at first* (24 inches), and sound it.

To produce *fa*, move the bridge so as to make the wire $\frac{3}{4}$ *as long as at first* ($22\frac{1}{2}$ inches), and sound it.

To produce *sol*, move the bridge so as to make the wire $\frac{2}{3}$ *as long as at first* (20 inches), and sound it.

To produce *la*, move the bridge so as to make the wire $\frac{3}{5}$ *as long as at first* (18 inches), and sound it.

To produce *si*, move the bridge so as to make the wire $\frac{8}{15}$ *as long as at first* (16 inches), and sound it.

To produce *upper do*, move the bridge so as to make the wire $\frac{1}{2}$ *as long as at first* (15 inches), and sound it.

1, $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, $\frac{1}{2}$, are the proportionate lengths which a string (whose tension is unchanged) must invariably have to produce the common scale. The eight sounds are called an *octave*.[1]

241. The Number of Vibrations of the Notes of the Scale. —According to the first law of vibrating strings, the number of vibrations of a string is *inversely* proportional to its length. Therefore, if we invert the fractions given above, we have the relative numbers of vibrations per second which are produced when the successive notes of the scale are sounded. They are as follows: 1, $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, 2. It will be noticed that the upper *do*, or C, is produced by exactly twice as many vibrations as the lower one. This note is called the *octave* of the one below, and this use of the word octave is rather more common than the use given in the preceding paragraph. When the octave of a note is sounded with the voice or with any instrument, twice as many vibrations are invariably produced.

If lower *do* is produced by 24 vibrations per second, how many vibrations will produce the succeeding notes of the scale?

---

[1] From the Latin *octavus*, meaning eighth.

242. **The Repetition of the Scale.**—In any scale the upper *do* is the *lower do*, or key-note, of the next octave. The sounds of this octave are denoted by the same names or letters as those of the octave below. The notes of this octave are produced by strings having the same proportion to the length of the string sounding its key-note as the notes of the octave below had to theirs. And the ratios of the numbers of vibrations are just the same as before. In the same way the scale is repeated in every seven notes *above* or *below* the one we have started with to the upper and lower limits of audibility (Art. 218). Every note, no matter how made, is produced by *twice* as many vibrations as the note of the same name in the octave below, *four* times as many as the one in the *second* octave below, etc.

Questions.—The upper *do* produced according to the directions given in Art. 240 was made by the vibrations of a wire 15 inches long: what must be the successive lengths of the wire to produce the notes of the octave above, of the second octave above, of the octave below?

If the key-note of a scale is produced by 24 vibrations per second, how many vibrations will be necessary to produce the notes of the octave above? of the second octave above? How many of the notes of the octave below can be produced? Why can they not all be produced?

243. **The Fixing of the Pitch of the Key-Note.**—Any pitch whatever may be taken for the key-note, and the different notes will range above or below this, according to the laws just given.

One person may sing a piece of music using a key-note of a certain pitch. A second person may take for his key-note the pitch which the first gave to *re* and sing the same piece through. Each of his sounds will of course be one note higher than those of the other singer. A third singer may take the pitch of the *sol* of the first for his key-note; and so on. This is very noticeable when different persons start tunes without the aid of instruments. The natural limits of the human voice, however, confine us in our choice of the pitch of the key-note to rather narrow limits, varying according to the compass of the singer's voice and the range of the piece of music sung. Leaders of vocal music often use tuning-forks in order to get the most suitable pitch.

Piano-tuners use tuning-forks or whistles, which always make a

certain known number of vibrations per second, and tune pianos by them. In the best American pianos middle C makes 268 vibrations per second.

244. Intervals between the Notes of the Scale vary.—The following numbers are the answers to the problem given in Art. 241, and are the *relative* numbers of the vibrations of the notes of any scale,—viz.: $\overset{\text{do}}{24}$, $\overset{\text{re}}{27}$, $\overset{\text{mi}}{30}$, $\overset{\text{fa}}{32}$, $\overset{\text{sol}}{36}$, $\overset{\text{la}}{40}$, $\overset{\text{si}}{45}$, $\overset{\text{do}}{48}$. *Re* is produced by $\frac{3}{24}$ or $\frac{1}{8}$ more vibrations than *do*, *mi* by $\frac{1}{9}$ more than *re*, *fa* by $\frac{1}{15}$ more than *mi*; from *fa* to *sol* and from *la* to *si* the increase is again $\frac{1}{8}$, from *sol* to *la* $\frac{1}{9}$, and from *si* to *do* $\frac{1}{15}$ again. Thus we see that in three of the intervals there is an increase of $\frac{1}{8}$ in the number of vibrations, in two of the others an increase of $\frac{1}{9}$, and in the remaining two an increase of only $\frac{1}{15}$. The five longer intervals are called *whole tones*, although they are not all of the same length, as we have seen. The two shorter ones are called *half tones*, although they are really longer than half of any of the whole tones, as you may see by comparing $\frac{1}{15}$ with the halves of $\frac{1}{8}$ and $\frac{1}{9}$. In every common scale the intervals between the notes are in exactly these proportions, and their order never varies.

A scale is sometimes used which is made by inserting an extra note in the middle of each whole tone: this gives us thirteen notes in the scale, all *about* the same distance apart. This is called the *chromatic*[1] *scale*. But it is not natural to sing the scale with half tones anywhere else than between the third and fourth and the seventh and eighth notes, so that few people can sing the chromatic scale. When any other than the natural half tones are wanted in a piece of music, the composer usually *transposes the scale;* that is, he starts with his key-note a little higher or lower than the *do* of the ordinary or *natural* scale, and thus brings the regular half tones just where he wants a half interval between two of his notes to come.

245. Temperament.—If a piano or an organ is tuned according to the natural scale, from C to D there is an increase of $\frac{1}{8}$ in the number

[1] From the Greek word meaning *color*, because these inserted tones used to be represented in colors.

of vibrations, from D to E of $\frac{1}{9}$, from E to F of $\frac{1}{15}$, etc. If, then, one should play upon such an instrument a piece of music in which the key-note is D, the interval between that and the next key would be only $\frac{1}{9}$ instead of $\frac{1}{8}$, so that it would not give correctly the second note of the scale. The next key, $\frac{1}{15}$ higher, would not be a correct half note between the second and third notes of our scale, as it should be, and so on through the scale. Not one interval in our scale would be correct. The same would be true of every other scale; none but the one in which the instrument was tuned could be played upon it correctly. This is partly corrected by the tuner distributing these errors equally over all the scales. This distribution of these errors is called *temperament*. The result is that no scale on a piano or an organ is absolutely correct, but the errors in any are so slight that most persons cannot notice them. If the instrument were tuned correctly for any one scale it would sound very badly when played in any of the others. The piano and the organ, therefore, are not perfect instruments, and can never make perfect music. But in the violin and the flute the pitch is controlled by the player, and they may in the hands of a skilful player produce perfect music.

246. **Beats.**—Experiment 79.—On a piano, or, better still, on a cabinet-organ, sound together the lowest key and the black key next to it. Mingled with the sounds of the two keys you will notice a peculiar quivering sound. These quivers, or bursts, of sound, which on the organ or piano are entirely too rapid to be counted, are called *beats*.

To understand the cause of these beats, we must go back to the interference of sound-waves, about which we learned in Art. 228. Let us suppose that two sound-waves, one vibrating 100 times per second and the other 101 times per second, start out together. At the start their condensations will coincide; they will strengthen each other and make a louder sound than either would alone. After half a second one is at the end of exactly fifty vibrations, and is, we may suppose, at its greatest condensation, but the other is at the end of fifty and a *half* vibrations, so that it must be at its greatest rarefaction. There the two sounds would destroy each other. At the *end* of the second the 100th condensation of one coincides with the 101st condensation of the other, and they strengthen each other

again. These will be repeated as long as the sounds can be heard. These alternate strengthenings and quenchings of the sound cause the beats.

It is clear that in the illustration just taken there would be one beat each second; and the same would be true with any two sounds, one of which vibrates once oftener than the other in a second. If one has 100 and the other 102 vibrations per second, at the middle one wave is at the 50th and the other at the 51st condensation. These strengthen each other *twice* in each second. Again, if one vibrated 100 and another 105 times per second, the 20th condensation of one would strengthen the 21st of the other; the 40th of the one, the 42d of the other; the condensations coincide five times, or there are five beats, each second. The number of beats in a second is equal to the difference in the number of vibrations which the two sounds make per second.

Beats can be made much better than on a piano or an organ by using two large tuning-forks of the same pitch, mounted on sounding-boxes, and loading one of them with a little wax. By increasing the wax the beats are made more frequent.

Beats are always produced when two notes of different pitch are sounded together. Generally they cannot be noticed, but nevertheless they have a most important effect upon the sound, as we shall see in the next paragraph.

247. **Harmony and Discord.**—"If, towards sunset, you walk on the shady side of a picket-fence, flashes of light will enter your eye every time you come to an opening between the pales. These flashes, coming slowly one after the other, cause a very disagreeable sensation in the eye. Similarly, if flashes or pulses of sound enter the ear, they cause a disagreeable sensation."[1] When two notes of different pitch are sounded together, beats are always produced. If these are *very* slow, the effect is not particularly disagreeable, but if they are numerous, as when any two contiguous keys of a piano or an organ are sounded, they produce a harsh sound, which we all recognize as a *discord*.

"But if the flashes of light or beats of sound succeed

[1] Mayer's *Sound*, pp. 174, 175.

one another so rapidly that the sensation of one flash or beat remains till the next arrives, you will have continuous sensations that are not unpleasant. In other words, continuous sensations are pleasant, but discontinuous or broken sensations are disagreeable."[1] If, therefore, the beats are *very* numerous, we have *harmony.*

For instance, when a note and its octave are sounded together, *every other* vibration of the upper note and *every* vibration of the lower coincide: we have the greatest possible number of coincidences or beats that two sounds of different pitch can have, and we have what is universally recognized as the most perfect harmony. When men and women sing together the same part of a piece of music, the women's voices are just an octave above the men's. Again, when *do* and *sol* are sounded together, every third vibration of *sol* coincides with every second vibration of *do;* the next most numerous coincidences that are possible produce what is well known to be the next best harmony. For the same reason the first and fourth notes, and the first and third, make pleasing sounds. But *do* and *re* only coincide at every eighth vibration of *do*, and *si* and *do* at every fifteenth of *si*. Here the beats are not rapid enough to be pleasant, and these make discords.

Why very many beats are agreeable and produce harmony, while a less number are disagreeable and produce discord, may be illustrated by remembering that a single cobweb, or even a considerable number of cobwebs, if brushed across one's face, tickle it very disagreeably; yet if these cobwebs could be woven into a piece of velvet, it would produce the same pleasant sensation that a piece of ordinary velvet does when rubbed over one's face.

248. **Harmonics.**—We have learned (Art. 232) that when a string, a reed, a column of air, or any other sound-producing body, is vibrating as a whole and thus producing its fundamental sound, it is at the same time generally vibrating in parts also, which produce the overtones. If only the *larger* parts are vibrating, as the halves, thirds, or fourths, or if the sounds of these predominate, we can now see that these would harmonize with the fundamental sound and with one another, and blending all together they would produce a pleasing sound. These lower overtones are therefore called *harmonics.* It is to them that we owe the pleasing effect of a sweet voice, of a lower or middle key of a good piano, or of any other single note that we

[1] Mayer's *Sound*, pp. 174, 175.

recognize as pleasant. But if the overtones are wholly or mainly the vibrations of the sevenths, eighths, ninths, etc., they will not harmonize with the fundamental note or with one another, and the result is a harsh sound. It is these that make a harsh voice, scraping on a violin, and other unpleasant musical sounds so disagreeable.

Experiment 80.—Strike middle C of a piano two or three times, so that you can recognize its sound when you hear it again, then press it down gently so as to make no sound, and hold it there, thus keeping the damper off the wire. Now strike the C, one octave below, vigorously, and, after holding that key down for three or four seconds, let it rise again. Its damper stops its sound at once, but you now hear a faint sound, which you recognize as that of middle C, which you are holding down. When you struck lower C it vibrated in halves, besides its vibration as a whole. And the vibrations of these halves set the wire of middle C to vibrating. In the same way you may hear the sympathetic vibrations of G above middle C produced by the thirds of the lower C. And possibly its fourths may set C, two octaves above it, in vibration.

Their overtones also have an effect upon the harmony or discord of two notes. To make them harmonious these two must make very rapid beats with each other and with the fundamental notes.

249. **The Human Ear.**—This organ is shown in Fig. 147. The end of the tube leading in from the outer ear is entirely closed by a thin membrane called the *tym'panum.* Behind this is a small cavity called the *drum* of the ear. This cavity is connected with the back part of the mouth by the *Eustachian* (yu-stā'ke-an) *tube.* A chain of four very small bones stretches across the drum from the tympanum to another smaller membrane that covers an opening into the *labyrinth.* This labyrinth is a small, curiously-shaped cavity in the solid bone of the

FIG. 147.—HUMAN EAR.

skull, and is filled with a watery fluid. The nerve of hearing runs from the brain to the labyrinth, and there divides up into thousands of microscopic branches, which stick out like bristles from the sides of the labyrinth into the liquid which fills it.

250. **How we Hear.**—The sound-vibrations enter the ear, strike the tympanum, and set it in vibration. Its vibrations are carried across the drum of the ear by the chain of little bones, and also by the air there, and set the membrane covering the openings into the labyrinth into vibration; and this communicates its vibrations to the liquid within. The tiny bristles which project into the liquid are of different lengths and thicknesses, and it is supposed that these are *tuned* each to a different pitch, and, in all, to all the pitches that are audible. It is likely, then, that the waves in the liquid which are produced by sound of a certain pitch set to vibrating the bristle which is tuned to the same pitch, and that the nerve-thread attached to this bristle conveys this impression to the brain and to the mind. When the sound contains overtones as well as the fundamental, each element of the sound must set in motion the bristle tuned to its pitch, and the combined impressions of these give us the true impression of the sound.

Exercises.—1. Why does touching a call-bell with your finger silence it?

2. There is believed to be no atmosphere of any kind on the moon: would this have any effect on sounds there?

3. Your pulse probably beats about 80 times per minute. Suppose that on a day when the temperature is at the freezing-point you count five beats of your pulse after you see the escaping steam of an engine-whistle, and before you hear its sound: how far off is the engine? *Ans.* 4087½ feet.

4. Suppose that on a summer day, when the thermometer stands at 80°, you count four beats of your pulse between a flash of lightning and the first sound of the thunder: how far off is the lightning?

5. A leader of a room full of singers is at one end of the room, which is 60 feet long. If the temperature of the room is 68° (which is about what it ought to be), how much will the words of the singers on the back seat seem to the leader to be behind his own? *Ans.* $\frac{60}{563}$ seconds.

6. What is the temperature of the air when the velocity of sound is 1150 feet per second? *Ans.* 92°.

7. Until recently the velocity of sound was always given as 1142 feet per second: what must have been the temperature when that result was obtained?

8. How far off is a barn when the echo of your voice comes back to you after you have counted three beats of your pulse, the temperature being at 60°?

9. The bell in the clock-tower at Westminster Abbey, London, is 300 feet above the ground: find the time sound takes to pass from the bell to a point on the ground 400 feet from the foot of the tower, the temperature being the same as in the last problem? *Ans.* $\frac{250}{559}$ seconds.

10. Could you set your watch to the second by the striking of a tower-clock some distance off? Why will a large company of singers keep better time if their leader beats time instead of leading them with his voice? How will it affect the drill of a long line of soldiers if the officer gives his commands while standing at one end of the line?

11. How much louder is a sound 50 yards from its origin than at a point 70 yards distant? *Ans.* As $\frac{1}{2500} : \frac{1}{4900}$, or as 4900 : 2500. Therefore $\frac{49}{25}$ as loud.

12. How much louder will a sound be 40 yards than 90 yards away?

13. What is the length of each wave of the lowest sound that we can hear? of the highest?

14. Give the difference between musical and non-musical sounds.

15. Explain the meaning and causes of *loudness*, *pitch*, and *character*.

16. Give an example of two musical sounds that agree in one of these characteristics only; of two others agreeing in two of them.

17. A certain string vibrates 100 times per second: find the number of vibrations of another string which is twice as long and weighs four times as much per foot and is stretched by the same force. *Ans.* 25.

18. A musical string vibrates 400 times per second: what takes place when the string is lengthened or shortened without altering the tension? when the tension is made greater or less without altering the length?

19. A tuning-fork vibrates over a jar 15 inches deep, and a strong resonance is produced: what is the rate of the fork's vibrations if the temperature is such that sound travels 1120 feet per second?

20. If *do* vibrates 264 times per second, how many vibrations in *mi* above it? in *sol*? in the upper *do*?

21. If *do* vibrates 264 times per second, how many vibrations produce *re*, *si*, and *fa* in the octave below?

22. Draw on the blackboard a line 30 inches long, and above it draw lines of the right proportions to represent strings which would give the notes of the octave above.

23. Middle C of a piano vibrates 272 times per second. In a seven-octave piano the lowest key is the fourth A below middle C, and the highest is the fourth A above it: what are the rates of vibrations of these two keys?

24. In a seven-and-one-third-octave piano the lowest key is the same as before, but the highest is the fourth C (four octaves) above middle C: how many more vibrations per second will the highest key of this piano make than the highest one of the other?

25. If *re* is produced by 216 vibrations per second, how many will produce *do* below? *re* below? *la* above?

26. Over how many octaves does the range of human hearing extend?

27. How many beats per second will there be when middle C and G above are sounding together on a piano? how many when B above is sounded with middle C?

28. If corresponding keys towards the upper end of the key-board be sounded together, will the beats be the same as in last problem? How will it be if they are taken in the lower end of the key-board?

CHAPTER VI.

LIGHT.

I.—THROUGH UNIFORM MEDIA.

251. Sources of Light.—Light comes to us from the sun by day and from the moon and stars by night. It is produced on the earth by combustion, by friction, by electricity, and by phosphorescence. Light from combustion is familiar in all fires. Light from friction may be seen by rubbing two pieces of white sugar together in the dark. The light from meteors (shooting-stars) is produced by the friction of small bodies moving with great velocity through the atmosphere. Light from electricity is visible when a cat is stroked vigorously in the dark. The lightning and the aurora are forms of this. Light from phosphorescence is often seen in decayed wood, in "luminous paint,"—a salt of calcium which glows when taken from a light place to a dark one,—and in a fire-fly.

Astronomy tells us that the sun is one of the stars, and that the moonlight is only reflected sunlight. Hence we may say that we have one celestial source of light,—the stars,—and four terrestrial sources,—combustion, friction, electricity, and phosphorescence.

252. **Cause of Light.**—In all these cases the light is produced in the same way. The particles of the body from which the light comes are put in extremely rapid vibration. The surrounding ether catches up these vibrations and carries them along like waves in water till they reach the eye of the observer, and the sensation produced is light.

253. **Light-Waves.**—Light-waves lie across the direction in which the light travels. If we suppose the ray of light to be moving perpendicularly to this page, the particles of ether vibrate up and down in *ab*, across in *cd*, and diagonally at all angles in *ef*, etc. The water-wave moves horizontally, while its particles vibrate up and down only. The method of vibration of the sound-wave has already been explained. The light-wave is different from either of these. Its particles move transversely to the motion of the wave in all directions. Its vibrations are very minute and very rapid. When a piece of iron is heated, its particles are set into vibration. At first this vibration is slow, and only affects the nerves sensitive to heat. But when the temperature is raised so that about 400 million million of them occur in a second, a red glow begins to show itself. Light is given out. When the temperature is further raised so that the number of vibrations is nearly doubled, the iron is white-hot. The intensity of the light is greatly increased. From 40,000 to 70,000 of these waves are in a linear inch.

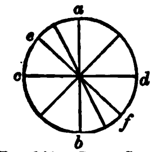


FIG. 148.—CROSS-SECTION OF RAY OF LIGHT.

254. **Light moves in Straight Lines.**—These vibrations are carried forward in straight lines so long as they do not meet with any change in the substance through which they pass. We always recognize this. We assume an object to be in the direction in which we see it,—that the light by which we see it carries the impression to the eye in a straight line. We can test the same fact by an experiment.

Experiment 81.—Arrange three cards by fastening them to blocks so that they will stand upright on a table. Pierce a small hole in each card, and place them so that a stretched string will go straight through all the holes. Now put a lamp in front of the end hole. It will shine through all. But if any of the cards be moved so that the holes are not in a straight line, the light will not shine through.

Experiment 82.—Darken a room, and make a small hole in a shutter opposite a white wall. Over this paste a piece of paper in which

a large pin-hole is pierced. The outside landscape will be projected on the wall inverted, for all the rays will cross at the opening. Rays from *a* will move in straight lines to *a′*, and rays from *b* to *b′*.

FIG. 149.—IMAGE THROUGH A SMALL HOLE.

Experiment 83.—Hold a candle in front of a card in which a pin-hole is pierced. The candle will be seen inverted on a small screen held beyond the hole.

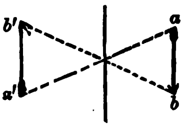


FIG. 150.—LIGHT MOVES IN STRAIGHT LINES.

Experiment 84.—Have made in a a temporary window-shutter a number of small openings of different shapes, and let the sunshine through into the room. Receive the image from them on a screen placed at a distance from the holes. These images will all be round, not the shape of the holes. They are images of the round sun.

The same may be seen in the light patches on the ground under a tree, formed by the passage of sunlight through the small openings of the foliage.

255. **Opaque, Transparent.**—When a body allows light to pass through it, it is said to be *transparent;* when it does not, it is said to be *opaque.*

Name several opaque and several transparent substances.

256. **Shadows.**—Shadows are a result of the motion of

light-waves in straight lines. If an opaque body be placed

FIG. 151.—IMAGE BY PASSING LIGHT THROUGH A SMALL HOLE.

between a source of light and the wall, a dark place is shown on the wall, which is due to the fact that the light which would otherwise fall on it is cut off by the opaque body.

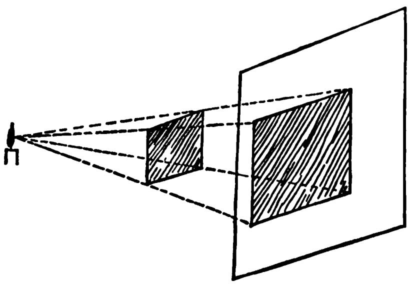


FIG. 152.—SHADOW.

Experiment 85.—Stretch a string from the source of light touching the edge of the shadow; it will touch the edge of the body.

Experiment 86.—Make the body a square, and place it exactly half-way between the light and the wall. Measure the shadow. Its side will be twice the side of the square, and hence its area will be four times that of the square.

257. **Law of Light-Variation.**—This last experiment explains an important law. The light which would have been spread over the space occupied by the shadow now is collected on the square, and therefore covers only one-fourth the space. Hence it is four times as intense on the screen as at the wall. The wall is twice as far from the light as the square is, and the intensity is only one-fourth as great. Were the wall three times as far away, the intensity of the light would be only one-ninth as great. The general law is, *Light diminishes as the square of the distance increases.*

258. **Photometry.**—We can compare the relative intensities of two lights by the aid of this law.

Experiment 87.—Place an opaque body in front of a wall, and arrange the lights so that the two shadows shall be side by side.

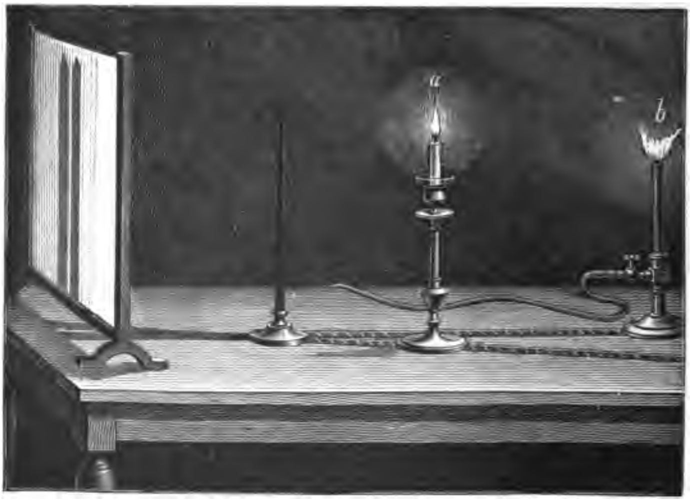


FIG. 153.—PHOTOMETRY.

Move one of the lights backward or forward till the shadows are of the same intensity of darkness. The shadow from *a* is still lit up by *b*, and the shadow from *b* by *a*. If the shadows are equally bright, the intensities of the light given by the two bodies at the wall are the

same. Now measure the distance of each light from the wall. The squares of these distances will be the relative intensities of the lights.

259. **Umbra and Penumbra.**—If the source of light, instead of being small, is of considerable size, we shall find that the

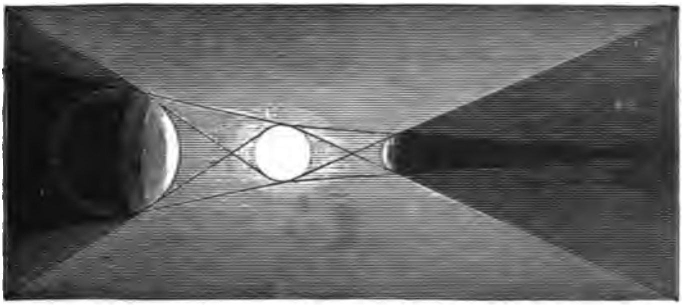


FIG. 154.—UMBRA AND PENUMBRA.

shadow is not definite in outline, but gradually shades out. The cause of this is shown in Fig. 154.

The portion directly behind the intercepting object does not receive any light from the source, and is called the *umbra.* The shaded portion on each side of this receives light from part of the source only, the part increasing as we depart from the umbra, and is called the *penumbra.*

The penumbra gives to the shadows of bodies a softness of outline which they do not receive when the source of light is very small. Moreover, as this penumbra increases in size as the distance from the body increases, this softness shows itself more conspicuously as we move the body away from its shadow.

Experiment 88.—Throw a shadow on a wall by a body close to it. Move the body away, and notice the change in distinctness of shadow.

260. **Velocity of Light.**—For a long time it was supposed that light was propagated instantaneously. Galileo took a lantern to the top of a mountain, and had an assistant on the top of another, where there were no intervening objects. He cut off the light suddenly, and told his assistant to cut

his off as soon as he missed the light from Galileo's. As he did not notice that it took any time between the extinguishment of the two lanterns, he concluded that the light took no time to travel. He erred only in this, that the time was too small to be detected by such rude means.

261. **Velocity obtained from Jupiter's Moons.**—The first idea that light had velocity was gained by examination of Jupiter's satellites. In the figure, TT′ represents the orbit of the earth around the sun, and JJ a part of Jupiter's orbit. Jupiter casts a shadow on the side away from the sun, and into this shadow plunge his little moons in their revolution about him. The time of these eclipses can be calculated in advance, and it has been found that when the earth is at T′ it appears to us earlier than when the earth is at T. The reason of this is that the light has to travel the distance from T′ to T, the diameter of the earth's orbit, farther in one case than in the other. The difference in time amounts to about 16½ minutes. As we know that the diameter of the earth's orbit is about 185,000,000 miles, we can readily calculate the velocity of light.

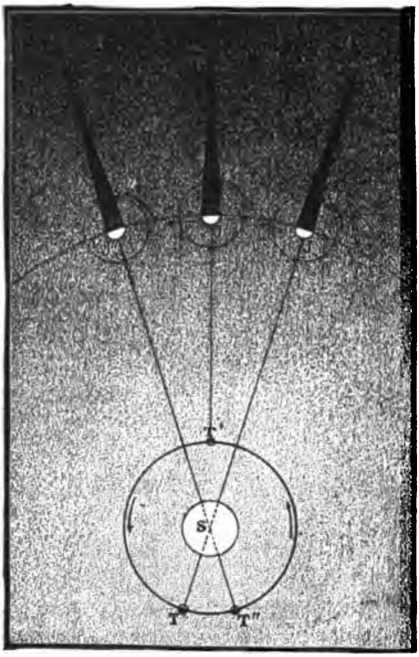


FIG. 155.—VELOCITY OF LIGHT BY ECLIPSES OF JUPITER'S SATELLITES.

Thus, 16½ minutes = 990 seconds:

185,000,000 miles ÷ 990 = 187,000 miles, nearly, per second.

262. **A Better Method.**—A still more accurate determination can be obtained by the following method: *a* is a mirror which can revolve about a vertical axis, *ef*. *b* is a stationary mirror. *g* is an opaque body containing a narrow slit. Sunlight is thrown through

this slit so that it falls on the mirror a, and is reflected to b, and back again to a. If a has not moved, the light would be again reflected directly to the slit in g. But a may be made to revolve with great rapidity, and during the minute time that the light has been travelling from a to b and back again, the mirror has changed its position a little, so that the light is now thrown to some other point, as h. Knowing the velocity of the mirror and the distance of h from the slit, it is possible to calculate the time required in passing twice between a and b. Now measuring the distance, the velocity of light is found.

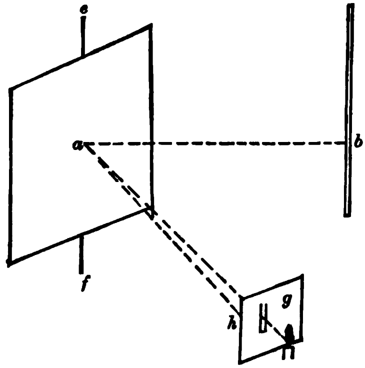


FIG. 156.—FOR FINDING THE VELOCITY OF LIGHT.

The best results obtained for the velocity of light are 299,940 kilometres, or 186,380 miles, per second.

Exercises.—1. A board 1 foot square is held between a point of light and a wall, parallel to the wall. If 2 feet from the light and 4 feet from the wall, what is the size of the shadow?

2. A coin casts a shadow on a wall to which it is not parallel: what is the shape of the shadow?

3. A lamp 8 feet from a wall throws a shadow which is just as bright as that thrown by a candle 2 feet from the wall: compare the light of the two.

4. Light requires about $3\frac{1}{2}$ years to come from the nearest star: how far is it away?

5. Does the fact that we see the stars prove that they are in existence at the present time?

6. How long would it take light to go to the moon? how long around the earth?

II.—REFLECTION.

263. Reflection.—When light falls on a smooth surface which it cannot penetrate, it is turned back, or *reflected.*

Experiment 89.—Allow sunlight to shine into a dark room through a small hole. The beam[1] will be visible by lighting up the particles

[1] This is better arranged by means of a *heliostat,* which reflects the light into the room. A sample one is described, together with a

of dust which are always floating in the air. It can be in this and other cases made still more evident by smoke from heavy brown paper. Let it fall perpendicularly on a mirror. The beam is turned directly back on its track. Turn the mirror 45°, the light goes off at right angles to its former course.

Experiment 90.—Allow the beam of light from the sun or a lamp to shine through a hole in a card at *d*, to fall on a mirror at *b*, and to be reflected on another card at *e*. Make a hole at *e* at the same height above *c* that *d* is above *a*. Look through the hole at *e* and see the light reflected from *b*. Mark the exact point where the light falls at *b*. Now measure *ab* and *bc*. They will be equal. We can readily prove from this by geometry that the angle *dbh* is equal to the angle *ebh*.

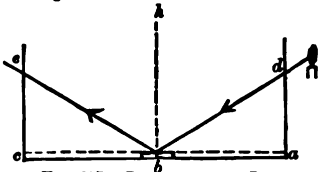


FIG. 157.—REFLECTION OF LIGHT.

264. Incident and Reflected Rays.—In Fig. 157, *db* is said to be the *incident* ray, and *be* the *reflected* ray; *dbh* is the *angle of incidence*, and *ebh* the *angle of reflection.*

265. Law of Reflection.—The general law of reflection is that *the angle of incidence is equal to the angle of reflection.*

266. Principle of Mirrors.—We may understand from

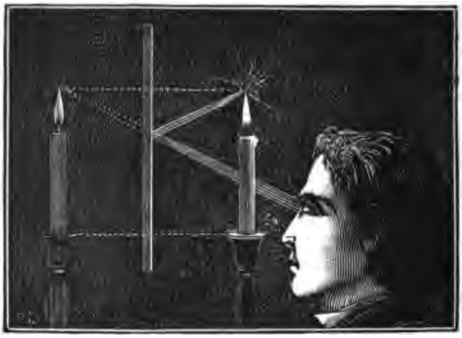


FIG. 158.—PRINCIPLE OF MIRRORS.

this and from Fig. 158 how it is that we see objects in a looking-glass. Objects are seen in the direction in which

number of interesting experiments to be performed with it, in *Light*, by Mayer and Barnard.

the rays of light from them enter the eye. The glass turns these rays back, making the same angle with the perpendicular that they had before, and we therefore seem to see them, back of the glass, the same distance from it that they are in reality in front of it, but inverted right and left. The image is not real: it is an optical delusion. Such images are said to be *apparent* images.

267. **Natural Objects.**—It is by the aid of reflected light that we see most natural objects. When the object is smooth, as a mirror, the light is reflected in parallel rays, and we notice only the glare; but when its surface is rough, such as that of a book or wall or landscape, the reflected light is diffused in all directions, and the object is seen by it.

268. **Multiple Images.**—We sometimes see more than one image of an object.

Experiment 91.—Take a mirror out into the starlight, and see the reflection of a bright star or planet at an oblique angle. The star will seem to be attended by a small companion. This is due to the reflection from the front face of the glass, as shown in Fig. 159. One

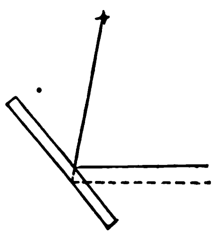


FIG. 159.—DOUBLE IMAGE.

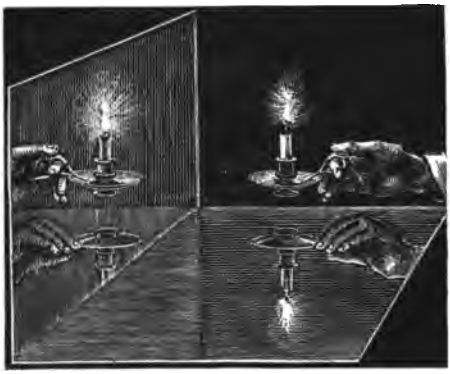


FIG. 160.—IMAGES BY TWO MIRRORS.

reflection comes to us from the silvered back of the mirror, the other, the fainter one, comes from the front face.

If two mirrors are inclined to each other, quite a number of images may be seen. Fig. 160 shows one case of this.

Fig. 161 shows the reason of this. If p is the candle, and e the eye

of the observer, he sees one object at p' by direct reflection from ab,

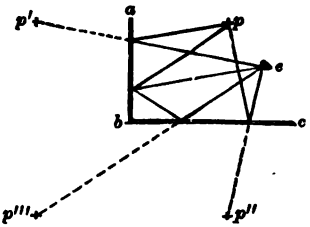


FIG. 161.—IMAGES BY TWO MIRRORS.

one at p'' by reflection from bc, and one at p''' by reflection first from ab and then from bc.

269. The Kaleidoscope.—The kaleidoscope is composed of three mirrors inclined at angles of 60° to one another, and arranged along the whole length of a tube. At one end the person puts his eye and sees a number of colored glasses at the other end, reflected and re-reflected from mirror to mirror, thus causing the appearance of symmetrical figures of great beauty. Fig. 162 shows a cross-section. The circle represents a tube, which may be of pasteboard. The straight lines are strips of glass (clear glass will answer) placed along it. An eye-hole must be at one end, and in the other some ground glass or oiled paper, or some semi-transparent substance. On this a few irregular pieces of broken colored glasses are scattered. These are kept in the bottom of the tube by a piece of clear glass.

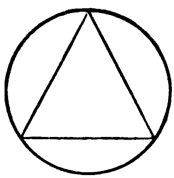


FIG. 162.—CROSS-SECTION OF THE KALEIDOSCOPE.

The ingenious student can make a kaleidoscope for himself.

270. Concave Mirrors.—Concave mirrors produce a different effect from plane mirrors. Let ab be an arc of a circle, and cd the direction of an incident ray of light. The perpendicular to the surface will always pass through the centre, f, of the arc, and the reflected ray will be in the direction de, making $cdf = edf$. Any other ray, as gh, parallel to bd, will be reflected in the line he, which will meet de in some point e. Hence the effect of a concave

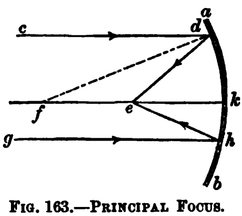


FIG. 163.—PRINCIPAL FOCUS.

mirror is to converge the rays of light, or to make divergent rays less divergent.

271. **Principal Focus.**—The point to which the *parallel rays converge is called the principal focus*, and is midway between *f* and *k*.

272. **Parabolic Mirror.**—If *ab* is a circle, all parallel rays will not meet in exactly one point. In order for this, *ab* must be a curve called a parabola (see page 43). Also, if

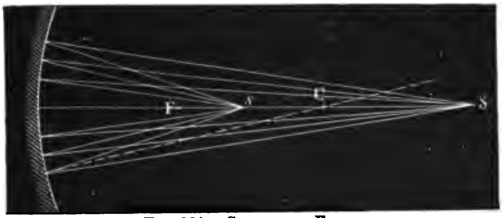


FIG. 164.—CONJUGATE FOCI.

a light be placed at *e*, the rays, after reflection, will all be parallel. This principle is used in making reflections for lanterns. The light is so placed inside the parabolic mirror

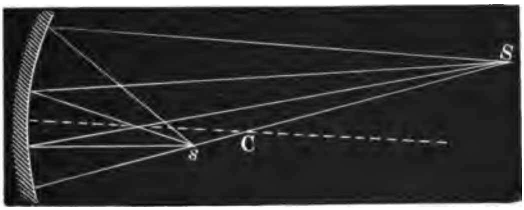


FIG. 165.—CONJUGATE FOCI.

that all rays which strike it are reflected forward in parallel or nearly parallel lines. The principle is also used in the mirrors of reflecting telescopes, where parallel rays from the heavenly bodies are brought to a focus, near which the eye is placed. If the rays do not come in parallel, but diverge from some point as *S* (Figs. 164, 165), they will converge to some other point as *s*. If they diverge from *s*, they will converge to *S*. *S* and *s* are called *conjugate foci*.

273. **Images by a Concave Mirror.** Let *ab* be an object

placed farther from the mirror than the centre, *c*. Now, whenever any bundle of rays proceeding from a single point are brought together at another point, an image is there formed. All rays from *a* will meet in a point at *a'*. This point can be most easily found by drawing the parallel ray, *ag*, and its direction of reflection through the principal focus, *gfa'*; also the ray, *ah*, through the centre, which is reflected directly back towards the centre. The intersection *a'* of *ga'* and *a'h* is the image of *a*. Similarly, the light

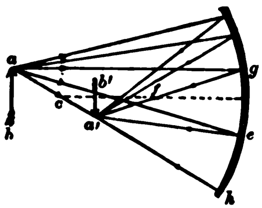


FIG. 166.—IMAGES BY CONCAVE MIRROR.

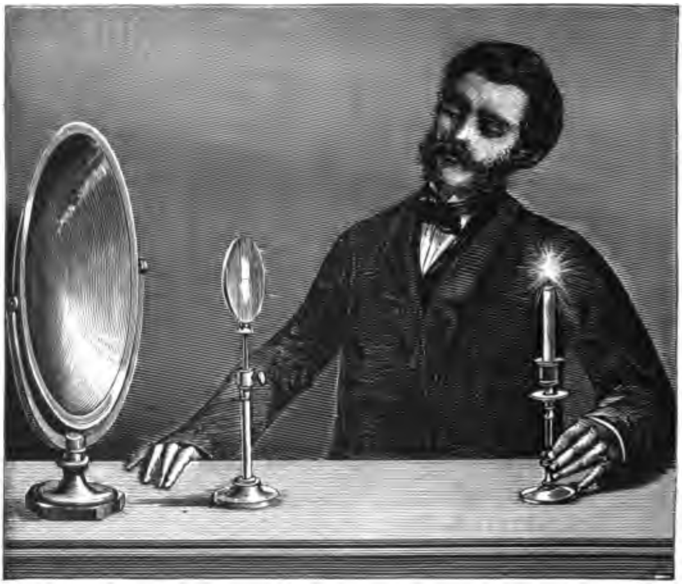


FIG. 167.—IMAGE BY CONCAVE MIRROR.

from *b* will be focussed at *b'*, and all points of *ab* will have corresponding points in *a'b'*. We shall then have a *real*

image, inverted and smaller than the object. By holding a piece of white paper at *a'b'*, we can, if it does not cut

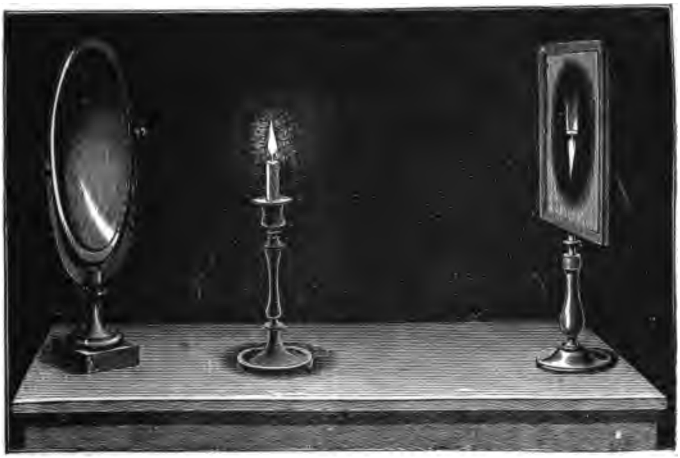


FIG. 168.—IMAGE BY CONCAVE MIRRORS.

off too many of the rays which would fall on the mirror from *ab*, see the inverted image.

If the object be placed at *a'b'*, the image will be formed inverted and enlarged at *ab*. (Fig. 166.)

Exercises.—Show by construction that (*a*) if the object be at the centre the image will be at the centre inverted; (*b*) if the object be at the focus there will be no image; (*c*) if the object be between the focus and the mirror there will be an image behind the mirror, apparent, erect, and magnified.

Experiment 92.—Take a glass concave mirror, or, if this cannot be had, a lantern-reflector, and verify the above in all the cases,—

1. By looking in the mirror at varying distances;
2. By placing a candle at different distances from the mirror and catching the image on a screen.

274. Convex Mirrors.—Convex mirrors cause parallel rays to diverge from a point behind the mirror, which is the principal focus. The images from a convex mirror are always behind the mirror, apparent, erect, and smaller than the object.

Experiment 93.—With a convex mirror of glass or "tin" examine

the truth of these statements by looking into it from varying distances.

275. Diffusion of Light.—The sun shines on the air, and the little particles of dust and vapor which it contains reflect the rays in all directions. This is the reason that sunlight gets into our rooms and under trees. This brings light to our eyes and enables us to see objects upon which the sun does not shine directly.

276. Twilight.—Twilight is produced by a similar cause. Even when the sun is below the horizon some of its rays are reflected to us by invisible particles in the atmosphere. As it gets farther down it shines only on the upper layers, and so the day gradually changes into night.

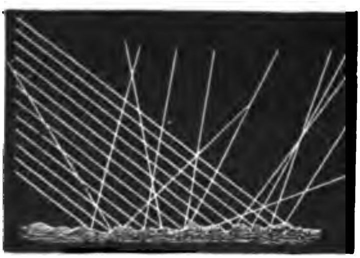


FIG. 169.—DIFFUSION OF LIGHT.

Objects are seen by the light which they diffuse. If the surface is very smooth, the light is reflected in parallel lines, and a glare is produced. If not, the light is reflected in all directions, and the features of the object are brought out.

Exercises.—1. Shall we notice double reflection when we look perpendicularly on a mirror? Draw a figure to show that the two images will be farther apart the more obliquely we see the object reflected from the mirror.

FIG. 170.

2. Draw a diagram to show that an object seen between two parallel plane mirrors will have its image several times multiplied.

3. Draw a diagram to show that a person can see himself in a mirror half as long as himself.

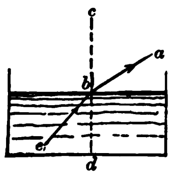
4. If the sun, 93,000,000 miles away, and an electric light, 20 feet away, cast shadows of the same intensity, how many times brighter is the sun than the electric light?

5. If there were no atmosphere surrounding the earth, why would the stars look like points of light in a black sky? why would all shadows be perfectly black? Do we see any rays of light except such as enter the eye? if not, how do we see a beam of light pass through a dark room?

III.—REFRACTION.

277. **Refraction.**—When light passes obliquely from one transparent substance to another, as from air to clear water, it is turned from its course, or *refracted.*

278. **Law of Refraction.**—This refraction is shown in Fig. 171. The course of the beam will be the same whether it passes from



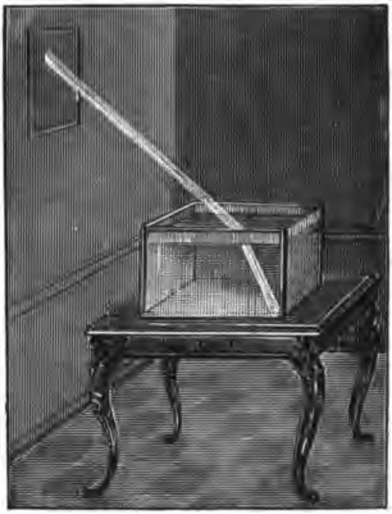


FIG. 171.—REFRACTION.

the air into the water or from the water into the air. The rule is, *when light passes from a medium into a denser medium, it is turned towards the perpendicular to its surface; when it passes into a rarer medium, it is turned away from the perpendicular to its surface.*

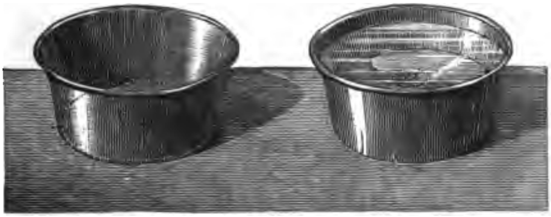


FIG. 172.—COIN MADE VISIBLE BY REFRACTION.

Experiment 94.—Place a coin on the bottom of a basin so as to be
m

just hidden by the edge. Pour water into the basin, the coin will come into sight. The rays which strike the surface of the water as *ab* (Fig. 171) are refracted in the direction *bc*, and enter the eye.

Experiment 95.—Place a stick obliquely in clear water, it appears bent: explain this.

279. **Angles of Incidence and Refraction.**—If the ray is passing from air into water, the angle *aIb* (Fig. 174) is called the *angle of incidence*, and *cId* the *angle of refraction.*

280. **Law of Sines.**—There is a law of refraction called the "law of sines." This may be explained by Fig. 174. If a circle be de-

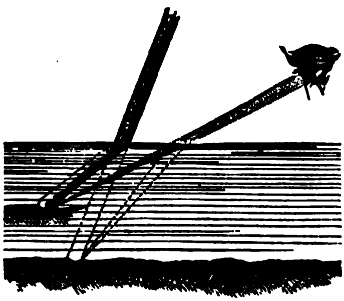


Fig. 173.—Stick bent by Refraction.

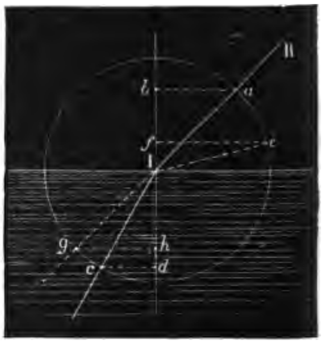


Fig. 174.—Law of Sines.

scribed about the point where the ray strikes the surface, and from the points *a* and *c*, where the incident ray and the refracted ray cut this circle, perpendiculars *ab* and *cd* be drawn to the vertical *bd*, then the "law of sines" is that *ab* has to *cd* a constant ratio, whatever be the angle of incidence. That is, if *ab* is 1½ times *cd*, any other line, *ef*, will also be 1½ times *gh*.[1]

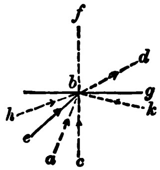


Fig. 175.—Limiting Angle.

281. **Limiting Angle.**—In passing into a rarer medium, the angle of refraction, *fbd*, is greater than the angle of incidence, *abc.* For a certain angle of incidence, as *ebc*, the angle of refraction becomes 90°, or *fbg*. This angle, *ebc*, is

[1] *ab* is said to be a *sine* of the angle of incidence, and *cd* of the angle of refraction. This is an expression used in Trigonometry; hence the name of the law.

called the *limiting angle.* In the case of air and water it is

FIG. 176.—TOTAL REFLECTION.

about 48½°. If the angle of incidence is greater than this, as *hbc*, the ray will not leave the water, but will be *reflected* from its surface, and pass in the direction *bk.*

FIG. 177.—TOTAL REFLECTION.

Experiment 96.—Hold a glass of water, with spoon, as in Fig. 177, so that we may look obliquely at the surface of the water from underneath. There will be *total reflection* of the part of the spoon under water.

282. **Total Reflection.**—This is called total reflection because all the light is reflected. This is not the case with ordinary reflection.

If a glass prism shaped

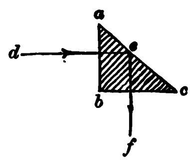


FIG. 178.—TOTAL REFLECTION.

like *abc* be so placed that the light will fall vertically on the face *ab*, it will pass into the glass. It cannot pass through the surface, *ac*, into the air, for the angle of incidence, is greater than the limiting angle. The light will suffer total reflection, and will pass off in a perpendicular, *f*, to its former course.

283. **Refraction through Glass.**—If light passes through a piece of glass with parallel sides, it is refracted by both surfaces in different directions, and emerges parallel to its original course.

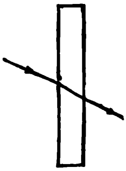


FIG. 179.—REFRACTION BY GLASS WITH PARALLEL SIDES.

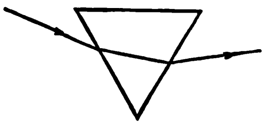


FIG. 180.—REFRACTION BY PRISM.

284. **Refraction through a Prism.**—If the sides are not parallel, the light emerges in a new direction.

Experiment 97.—Procure a thick piece of clear glass and hold it so that part of an object shall be seen obliquely through it and part past the edge. The two parts will not fit together.

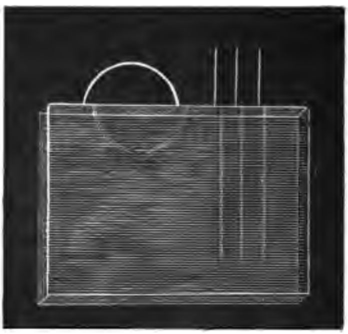


FIG. 181.—REFRACTION BY PLATE-GLASS.

Experiment 98.—Procure a glass prism, and notice the apparent change of position of objects seen through it. (The colors seen will be explained farther on.)

285. **Explanation of Refraction.**—The effects of refraction have

been illustrated in the following way. Suppose a combination of two wheels and an axle to be moved over the floor. It will, if the floor is

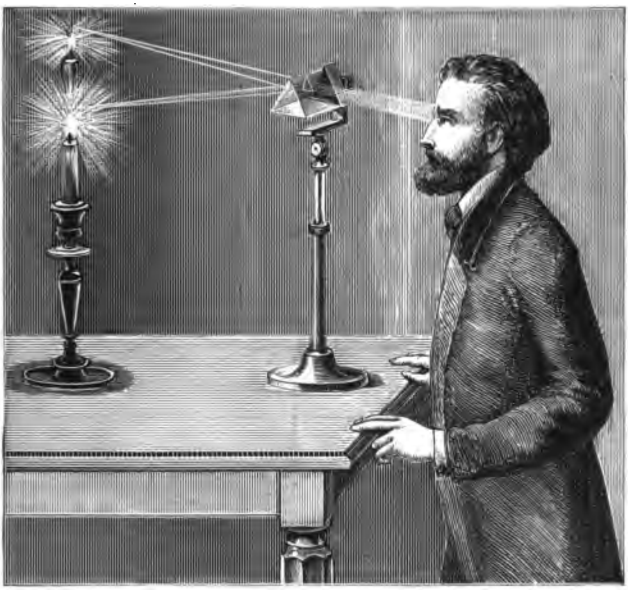


FIG. 182.—REFRACTION BY TRIANGULAR PRISM.

smooth, roll in a straight line. But if it comes obliquely against a square piece of velvet, the wheel that strikes first will be delayed, and

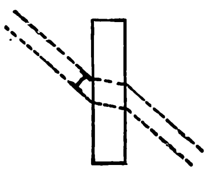


FIG. 183.—EXPLANATION OF REFRACTION.

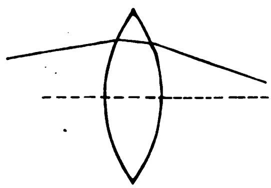


FIG. 184.—REFRACTION BY CONVEX LENS.

the path will be bent towards the perpendicular to the surface. When it gets to the other side, the same wheel will reach the smooth floor first and be accelerated, and so the path will be parallel to its original direction.

If the piece of velvet is convex, the effect will be to bend the path in the same direction at each surface; if triangular, as a prism does.

286. Lenses.—A *lens* is a circular piece of glass to refract the rays of light. At least one of its surfaces must be

FIG. 185.—LENSES.

curved. It may be of any of the following shapes: *a*, double-convex; *b*, plano-convex; *c*, concavo-convex; *d*, double-concave; *e*, plano-concave; *f*, convexo-concave.

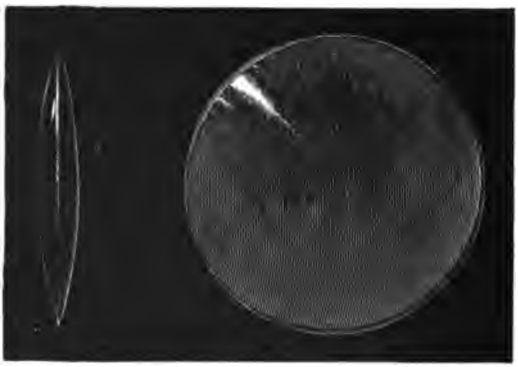


FIG. 186.—CONVEX LENS.

287. Effect of a Convex Lens.—The effect of a convex lens is to cause rays of light to converge.

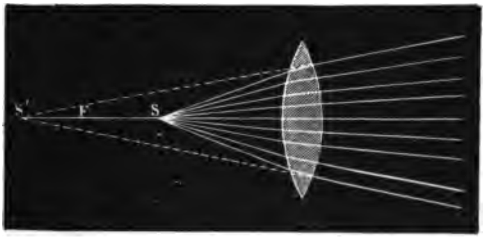


FIG. 187.—EFFECT OF A CONVEX LENS.

288. Effect of a Concave Lens.—The effect of a concave lens is to cause rays of light to diverge.

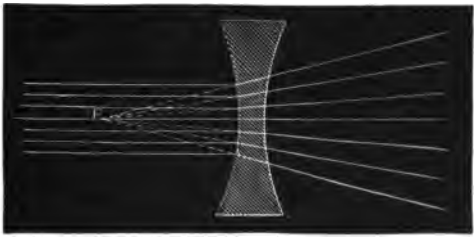


FIG. 188.—EFFECT OF A CONCAVE LENS.

Experiment 99.—Verify the first of these statements by means of glasses from spectacles, or "magnifying-glasses." Light is concentrated to a point.

To illustrate the properties of lenses we will study the cases of double-convex and double-concave lenses of the same curvature on both sides. This, with a knowledge of the principles of refraction, will enable any one to understand the effects of other lenses.

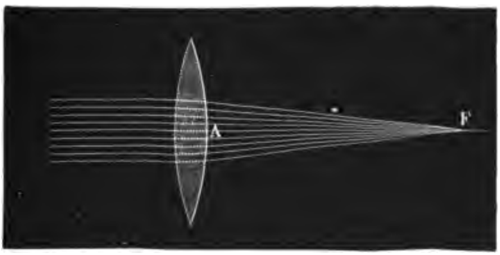


FIG. 189.—PRINCIPAL FOCUS.

289. Double-Convex Lens.—A double-convex lens will

bring parallel rays to a point called the *principal focus.* The distance from the centre of the lens, A, to the principal focus, F, is called the *focal length* of a lens.

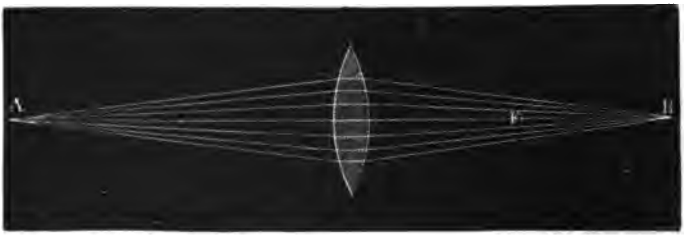


FIG. 190.—CONJUGATE FOCI.

If the rays diverge from a point, as A, they will converge to another point, as B, farther from the lens than the

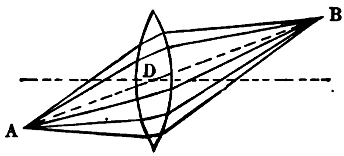


FIG. 191.—CONJUGATE FOCI.

principal focus. If they diverge from B, they will converge at A. The line joining A and B will always pass through the centre, D, of the lens.

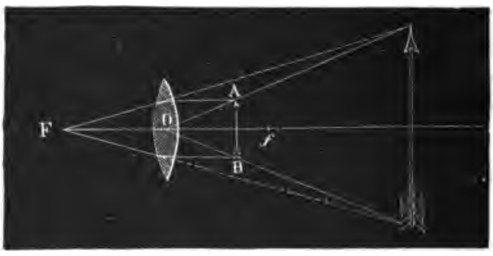


FIG. 192.—MAGNIFYING EFFECT OF A CONVEX LENS.

A and B are called *conjugate foci.* If the eye be placed at F, the converging of the rays from any object beyond

the lens, as AB, will cause an enlarged image of the object, as A′ B′. The rays from A appear to come from A′, and the rays from B appear to come from B′, and so for intermediate points.

The eye and the object must be in the conjugate foci of the lens for distinct vision.

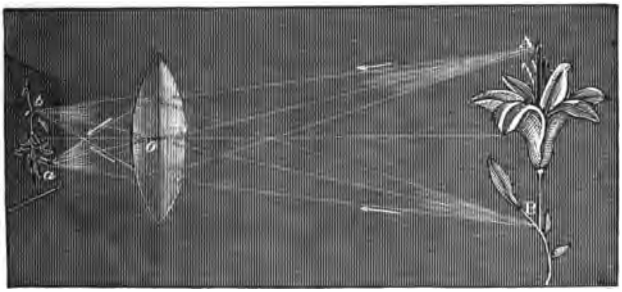


FIG. 193.—IMAGE BY CONVEX LENS.

FIG. 194.—IMAGE BY CONVEX LENS.

Experiment 100.—Hold a magnifying-glass so as to see an object distinctly. Now move the object from the lens. The eye must be placed closer to the lens to secure distinct vision. As one focus recedes from the lens, the other approaches.

Experiment 101.—Hold a lens in front of a wall or a piece of paper

so that the light of a candle will shine through the lens. By moving the lens to and from the wall, the position is found where an image of the candle will be cast on the wall or paper, inverted.

Experiment 102.—Try the same in the daytime in such a way as to throw an image of the window on the wall.

Experiment 103.—When a distinct image of a distant window or candle is thrown on the wall, measure the distance of the lens from the wall. This will give approximately its focal length; for the rays are nearly parallel.

Experiment 104.—Hold the lens in the direct rays of the sun; adjust it so as to make the circle of light on the screen the least possible. Measure again from the screen to the lens. This should agree with the last measure. The circle of light is the image of the sun.

Fig. 195 shows why the object is inverted. All rays from *a* are brought to a focus in a line through *o* at *a'*, from *b* at *b'*, from *c* at *c'*, etc. When the object is nearer the lens than the image the image will be enlarged, and *vice versa*.

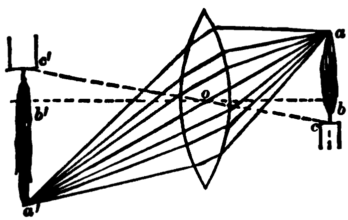


FIG. 195.—IMAGE BY CONVEX LENS.

Experiment 105.—In the arrangement of Fig. 195 move the candle nearer the lens; the image will recede and get larger.

Experiment 106.—Having found the focal length by experiment 104 or 105, place a candle at just twice the focal length from the lens; the image will be the same size as the object.

Experiment 107.—Place the candle at the principal focus. There will be no image, for all the rays move out parallel.

Experiment 108.—Place the image still nearer the lens. The rays will diverge, and will form no real image.

290. **Construction of the Image.**—The position and size of the real image can be constructed in the various cases as follows.

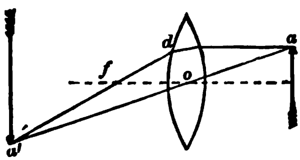


FIG. 196.—CONSTRUCTION OF THE IMAGE.

Draw the parallel ray *ad*. It will be refracted through the principal focus *f*. Also draw the line *ao* through the centre. Where these meet will be the position of the image of the point *a*. The same may be done from other points.

291. **Concave Lens.**—Since a bundle of rays from a point

are made to diverge still more by concave lenses, they do not form real images. The images are smaller than the objects, and are erect.

The principal focus is the point from which parallel rays appear to diverge.

292. **Spherical Aberration.**—A *spherical* convex lens will not bring all rays to exactly the same point. The rays near the edge are refracted more than those near the centre. Thus, while rays like *ab* are brought to a focus at *c*, those like *ed* are refracted to *g*, and hence a perfectly distinct image is not formed. This is called "spherical aberration," and has to be corrected for by deviations in the lenses from the spherical form.

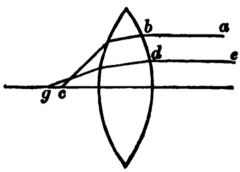


FIG. 197.—SPHERICAL ABERRATION.

293. **Atmospheric Refraction.**—When a ray of light enters the atmosphere from the sun or a star, it is refracted; as it enters each denser layer, it is more and more refracted, being always bent towards the perpendicular to the surface, so that it finally enters the eye as if it came from a point higher up in the sky than it really does. The effects of this are principally important to astronomers.

294. **Mirage.**—In hot and sandy deserts the surface layers of air are sometimes so expanded by the heat as to be rarer than those above. Rays from a distant object are then bent

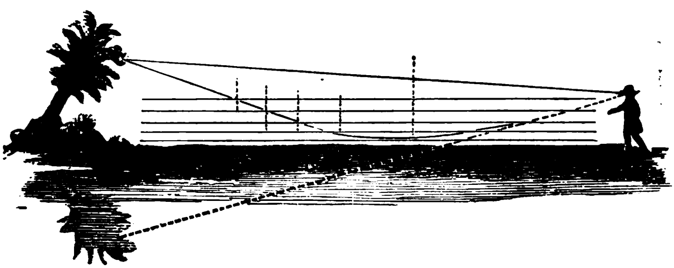


FIG. 198.—MIRAGE.

in the other direction, until finally, reaching the lowest angle, they suffer total reflection. These strata from which the objects and sky are reflected appear as a glassy pool. The illusion is called *mirage*.

IV.—DISPERSION.

295. Dispersion.—When light passes from one medium into another of different density, the light is not only refracted, but the image of the object is seen to be surrounded by a fringe of color.

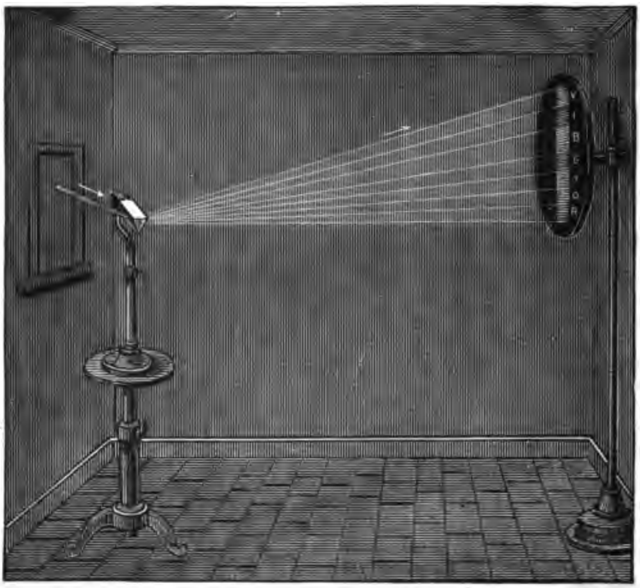


FIG. 199.—DISPERSION OF LIGHT.

Experiment 109.—Look through a prism of glass, and notice the colored fringes surrounding objects. Allow the direct rays of the sun to shine through the prism, and notice the rainbow-colors thrown on the wall or on any object in the room.

Instead of a glass prism it is much better to use a triangular bottle filled with carbon bisulphide.

Experiment 110.—With such a prism, allow a beam of light to pass into a room through a narrow slit. Or obtain a beam from a projecting lantern, and pass it through the slit. Place in front of the slit a prism of glass, which may often be obtained from off a lamp. Or, better, directly in front of the slit place a double-convex lens in such a position as to throw a well-defined image of the slit on a wall or a screen. In the path of the light, after passing through the lens, set a carbon bisulphide prism. A beautiful band of colors will now be seen on the wall, not, however, directly in front of the slit.

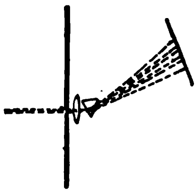


Fig. 200.—Dispersion.

296. **Spectrum.**—This band of colors is called a *spectrum*, and the separation of the beam of light into the various colors is called *dispersion.*

297. **Order of Colors.**—By an examination of the spectrum it will be seen that the colors are arranged in this order,—violet, indigo, blue, green, yellow, orange, and red; that the violet is refracted from its straight course the most, and the red the least.

298. **Cause of Spectrum.**—We may now see the cause of the spectrum. All these colors existed in the beam of light as it came through the slit. But the prism refracted them differently, turning the violet aside the farthest, then the indigo, and so on, and projecting them at different places on the screen. If they are all united, the original white light will be produced.

Experiment 111.—Hold a mirror in front of the prism so as to throw the spectrum on the ceiling. Rapidly rotate the mirror, so that the colors shall blend together on the ceiling. The image will now be white.

299. **Color-Disk.**—A color-disk is a circular piece of pasteboard, on which are pasted sectors of colored paper containing the rainbow-colors. When this is rapidly revolved, the colors all blend together in the eye and make white or gray.

If the colors were perfectly pure and well lighted up,

the disk would be entirely white. The gray tint is produced by the impurity of the colors.

FIG. 201.—COLOR-DISK.

300. **Waves of Different Lengths.**—It has been said that light is propagated in waves. All waves of light are not, however, of the same length, nor do all have the same quickness of vibration. Experiment has shown that the vibrations of the violet rays are shorter and more rapid than those of other colors, the indigo next, and then in the order of arrangement in the spectrum. When light made up of all these waves strikes the prism, the short, quick vibrations of violet are turned aside the most, and the larger and slower vibrations of red the least. This is the cause of dispersion.

Experiment 112.—Stand with the eye in the spectrum looking towards the prism. The different colors will be seen in order as the eye changes from side to side.

301. **The Spectroscope.**—This explains the spectroscope. In the end of the right-hand telescope is a narrow slit,

through which the light enters. The eye looks towards the prism through another telescope, which magnifies ob-

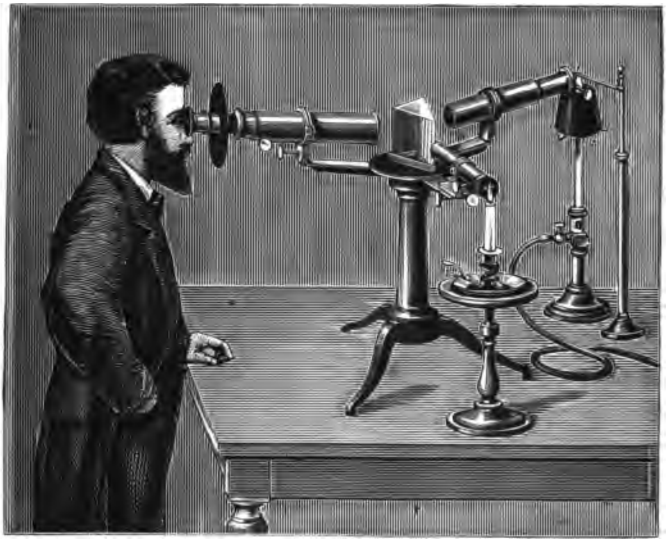


FIG. 202.—THE SPECTROSCOPE.

jects, and sees the spectrum directly. The third telescope is for the purpose of throwing a scale into view, so as to determine the positions of the various colors.

When used for celestial objects, this is attached to the eye-end of a telescope, so that the light from the object after going through the telescope will pass into the slit.

302. **Effect of a Train of Prisms.**—If the light, after passing through one prism, falls on another, the spectrum will be further dispersed. By using more prisms the spectrum may be made of any required length, though each dispersion causes a loss of some light, due to reflection from the faces of the prism.

303. **Different Spectra from Solids and Gases.**—Light coming from glowing lime, or from the heated carbon particles in the flame of a lamp or candle, will give similar

spectra, differing only in brightness. If, however, the spectrum of glowing *vapor* of sodium, made by sprinkling a little common salt in an alcohol, or Bunsen burner, flame, be examined with a spectroscope, it will be seen to consist of one or two[1] yellow bands only. There will be no red, green, or any of the other colors. If a vapor of strontium be formed in the same way, there will be bands or lines of red, yellow, and blue, and not of the others. In this way every substance has its own peculiar lines when reduced to the state of a glowing gas and examined with a spectroscope. We may thus judge of the composition of a substance by the character of its spectrum. *Glowing solids and liquids give continuous spectra, the colors running into one another, and all are alike. But gases give spectra of bright lines, and each gas has its peculiar spectrum.* Several are shown in the frontispiece.

304. **Dark-Line Spectra.**—If the light passes from a glowing solid through a gas, the spectrum shows all the colors; but it is crossed by dark lines, and the most careful measurements, as well as theory, show that these lines are in *the exact position of the bright lines which the gas gives out by itself.* Thus, if the light passes through sodium vapor there are seen in the yellow of the spectrum two dark lines side by side. If in examining a heavenly body we found such a spectrum as this, it would therefore indicate the composition of the vapor through which the light passed, but not the composition of the substance giving the light; the position of the dark lines would tell of the vapor which made them, while the continuous spectrum would not tell the character of the substance giving the light, except that it was not a gas under ordinary pressure.

305. **Solar Spectrum.**—The solar spectrum is seen in the frontispiece. We infer from this that the sun is a glowing

[1] There are two, but so close together that often they are not separated.

solid or liquid substance, and has an atmosphere of gas, which produces the dark lines.

306. **Cause of the Dark Lines.**—The cause of these dark lines is as follows. *A gas has power to take from light the same vibrations which it gives out when glowing.* When light from glowing lime shines through sodium vapor, the vapor abstracts from the light the particular vibrations that make up yellow light. The dark lines therefore indicate the absence of the spectrum in those positions. It is true that the vapor gives its own bright yellow lines, but they are faint compared with the spectrum from the solid, and hence look dark by comparison.

307. **Convergence of Spectra.**—As a glowing gas becomes cooled down, the bright lines which it shows in the spectrum broaden into bands, till finally, when it cools down to the state of a glowing liquid or solid, the bands run together, and a continuous spectrum is formed. This shows that the two kinds of spectra are not so distinct as would at first be supposed.

308. **Heat-Rays.**—The rays which convey the impression of heat from a glowing solid are also refracted and dispersed by a prism. They are the same rays as the light-rays, and extend also on both sides of the visible spectrum, more especially on the red side. The rays by which photographing is done lie principally about the violet end of the spectrum.

309. **The Sun Blue.**—Prof. Langley has recently shown that the atmosphere quenches much more of the rays near the violet end than of those near the red end of the spectrum, and that if we could see the sun outside our atmosphere it would appear blue rather than yellow, as it does.

310. **The Rainbow.**—The rainbow is a spectrum. Raindrops are the prisms. Whenever a ray of light enters one of these drops there is refraction, and wherever there is refraction there is dispersion.

The red is on the outside of the arc, and the violet on

the inside. When there is a fainter secondary bow the order of colors is reversed. The radius of the arc is about 41°,[1] and its centre is always exactly opposite the sun.

When the sun is just setting, how much of a circle is seen? how near to the horizon must the sun be to make a bow?

The path of the rays through a drop is seen in Fig. 203. From S the rays come, are refracted at I, reflected at A, and

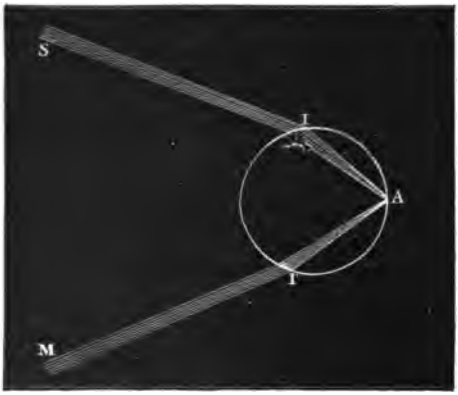


FIG. 203.—PATH OF RAYS TO FORM PRIMARY BOW.

again refracted at I′, and pass out dispersed towards M. The lines SI and I′M make an angle of about 41° with each other. Hence a person standing so that he would receive these rays, I′M, would have them colored. But the air is full of drops. Those in such a position at any instant as to send the ray to the observer would always be 41° (for

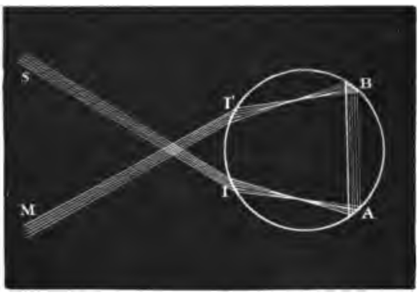


FIG. 204.—PATH OF RAYS TO FORM SECONDARY BOW.

[1] A little less than half the distance from the horizon to the zenith.

the red 42½°, and for the violet 40½°) distant from the point opposite the sun, and hence would lie in an arc of a circle.

Other rays which enter the drop are also refracted, but only those which pass as in the figure are kept together so as to make an impression. The remainder are scattered.

The secondary bow is produced by two refractions and two reflections, as in Fig. 204.

Fig. 205 shows the formation of both bows. *a* and *a′* indicate the position of the drops which form the violet rays, and *b* and *b′* that of the drops which form the red rays.

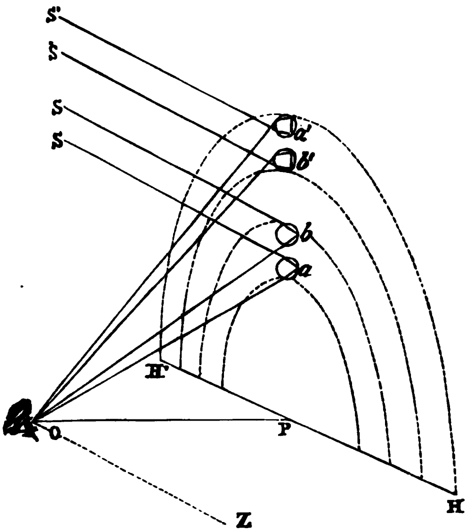


FIG. 205.—FORMATION OF PRIMARY AND SECONDARY BOWS.

311. **Halos.**—Halos are circles of light around the sun or moon, formed by refraction from crystals of ice floating in the air. They are seen in summer as well as in winter, for the cold of the upper regions makes ice-crystals at any time of the year. When formed by the sun, there is often sufficient light to show the colors of the rainbow.

A section of an ice-crystal is often of the shape of a six-sided figure. When rays enter one face they are sometimes refracted so that they emerge from the next face but one. This forms the smallest and most common halo, with a radius of about 22°. Sometimes the rays enter a side and come out at the base. This makes a larger and fainter halo.

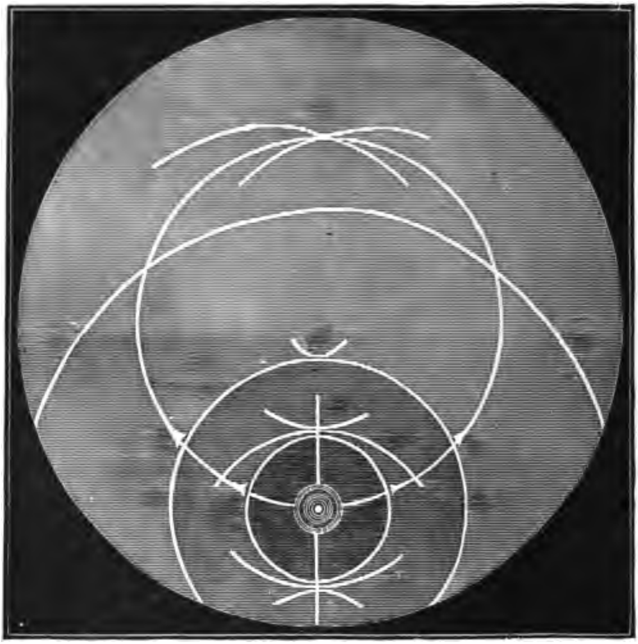


FIG. 206.—HALOS AND PARHELIA.

312. **Parhelia.**—There is often also a circle of *white* light parallel to the horizon, formed by *reflection* from crystals of ice suspended vertically in the atmosphere. This cuts the halos in two points. In these points the light is concentrated, some coming from the halo and some from the circle of reflection, and *parhelia* (otherwise called "mock suns," or "sun-dogs") are formed.

In Fig. 206, the bright spots are parhelia. The various curves are produced by varied refractions and reflections.

Fig. 207 shows circles seen in the United States in January, 1883. In this case parhelia were noticed at C, D, C′, and D′, even though no halos were seen from C and C′ and D and D′. Distinct ones were noticed at A, B, A′, and B′, and two colored halos.

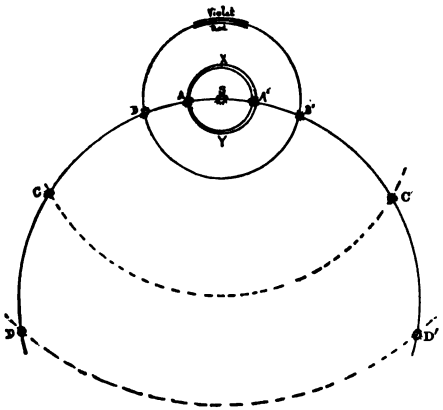


FIG. 207.—HALOS AND PARHELIA OF JANUARY, 1883.

313. **Colors of Opaque Objects.**—It has been said that the light which opaque objects diffuse is that by which they are seen. But the light which they diffuse after it has entered slightly within their surfaces is generally different from that which falls upon them. Their surfaces have the power of choosing out certain rays from the white light which is incident to them, and of destroying them. The remainder is diffused, and gives the objects their colors. If the colors of the red end of the spectrum are absorbed, the object will appear of some shade of blue. If the red and blue are both absorbed, the remaining colors will mix, and the general effect will be green. If nothing is absorbed, the color is white; and if all is absorbed, the object will appear black.

314. **Colors of Transparent Objects.**—If the object is transparent, it may be seen by the color which it transmits. Blue glass transmits the blue rays, and quenches or reflects the rest. Sometimes a piece of glass is seen to be of one color by transmitted light and of another color by diffused light.

Experiment 113.—Place a piece of blue glass in the path of the light which passes through the prism. The red end of the spectrum will be quenched, the blue end will be undisturbed. Try the same with glass of different colors.

315. **Cause of Blue Sky.**—The little particles of aqueous vapor and other things which exist in the air are so minute as to reflect only the short blue vibrations. Hence the sky appears blue by reflected light. When near sunset, the sun is shining through a great stretch of air.[1] The blue is largely taken out of his rays by this process of reflection, and the red is transmitted to the eye. The blue rays make the blue sky of places west of us. The clouds being lit up by this red light which remains, seem to be of a ruddy color. If there are no clouds, the strata of air nearest the horizon are of a reddish hue, which hue imperceptibly shades into the blue of the zenith through the intermediate shades of the spectrum,—orange, yellow, green,—more and more of reflected blue light being mingled with the transmitted red as we recede from the horizon.

316. **Primary Colors.**—All the colors seen on the earth are composed of one of the colors of the spectrum or of several of them blended together. Furthermore, all the colors of the spectrum are composed of one or more of the three *primary colors*,—red, green, and violet. Red and green mixed in varying proportions produce the colors which lie between them, and green and violet the rest. Red and violet produce shades of purple. Therefore, also, red, green, and violet produce white.

Experiment 114.—Collect together a number of objects of different colors in a dark room, and light them up by the light of a sodium taper, made by holding metallic sodium or common salt[2] in the flame of a Bunsen burner or an alcohol lamp. If the flame is bright enough, the effect is very striking. Yellow colors are brought out plainly. All others appear dark or of some shade of gray.

317. **Only Yellow in Sodium Flame.**—It has been shown

[1] Show this by a diagram.

[2] A pine stick soaked in a solution of salt will answer well.

that when the sodium flame is analyzed by a spectroscope nothing is found in it but yellow light. Hence, when it falls on objects, only those which can diffuse yellow light are colored. The others quench it and appear dark. An object cannot appear red or green, because no light containing these colors falls on it.

Experiment 115.—Place a strip of red paper in the red part of the spectrum. It will appear of its natural color. Place it in the blue. It will appear black. Red paper quenches blue rays and diffuses red. Try the same with paper of other colors. Most colored objects are colored by a mixture of the spectrum colors: hence they may reflect more than one.

318. **Complementary Colors.**—We have said that red, green, and violet produce white. Hence a mixture of green and violet, as bluish green, will produce white when combined with red. Also, since purple is a combination of red and violet, purple and green colors will produce white. Two colors which, when mixed together, produce white are called *complementary colors*. The mixture of any two of the primary colors is complementary to the third. We can obtain complementary colors by combining violet with bluish green for one shade, and red with yellowish green for the other. The whole spectrum must be included in the two colors. The names of some of the prominent complementary colors are as follows:

Red and bluish green.

Orange and turquoise-blue.

Yellow and ultramarine.

Yellowish green and violet.

Green and purple.

Two colors which are complementary show in contrast to better advantage than two others.

319. **Blue and Yellow.**—If solutions of aniline-yellow and ammoniacal sulphate of copper be placed in tanks with parallel sides, and light be passed through them so as to be thrown on the screen in the same place, the mixture of the blue and yellow colors will produce white.

Experiment 116.—Make two solutions of blue and yellow liquids, and pour them together; the resulting liquid will be green.

The green is produced because the blue liquid allowed the colors from green to violet to pass, and the yellow those from green to red. Green is the only color which both allow to pass, hence the mixture as seen by transmitted light is green.

320. **Effects of Complementary Colors.**—After the eye has seen one color for a time, it gives to other objects the complementary color.

Experiment 117.—Make a broad black ink-mark on green paper, and cover it with white tissue-paper. The mark will appear red.

This is an optical illusion. The eye is filled with green rays, and the tendency is to see other objects of the complementary color. The white tissue-paper tones down the intense blackness of the mark, which would otherwise, by its distinctness, prevent the illusion.

321. **Interference of Rays.**—Color is sometimes produced by *interference* of waves of light. This means that two waves so meet each other that the depression of one corresponds to the elevation of the other, so that they neutralize each other, as we have seen in the case of water-waves (page 87). If in white light the colors of the red end of the spectrum are thus neutralized, the resulting effect is blue. If the blue and the red are neutralized, the color may be green.

322. **Colors of Soap-Bubbles.**—This effect is seen in soap-bubbles.

Experiment 118.—Make a liquid out of good Castile soap and a little glycerine and water, and blow some soap-bubbles. Notice how beautifully the colors chase one another over the film.

The light is reflected to us from the outer and also from the inner surface of the film. If the thickness of the film is just a quarter of a wave-length, the light that comes from the inner surface, having to pass twice through the film, is just one-half a wave-length behind that which is reflected by the outer. If the film were three-quarters of a wave-length thick, it would be one and a half wave-lengths behind; and so on. In all these cases there would be destruction of light-waves. As the film is continually changing its thickness, and as the

wave-lengths of the different colors vary, there is a continually changing view of colors seen on the bubble.

323. **Diffraction.**—Another effect of interference is shown in what is commonly called *diffraction*. If light passes through a very narrow opening, fringes of color are seen along its sides. These are due to the fact that the waves of light radiating in all directions from the opening come in contact, and certain vibrations destroy one another, leaving the resulting colors.

324. **Gratings.**—Another form of diffraction is produced by substances whose surfaces are covered with parallel lines very close together. This is shown in mother-of-pearl shells, where the edges of the layers constitute the lines. This is caused by interference of the rays reflected from the different surfaces. Glass or any metallic surface ruled by fine lines affords an excellent substitute for a prism in a spectroscope. The diffraction spectra are not so bright as the prismatic from the same source, as not nearly all the light is reflected, but the colors are purer. The finer and closer the lines, the better will be the spectrum.

Exercises.—1. What difference is there between the causes of the color of a red book and of red glass?

2. Why are some objects of different colors by candle-light from what they are by daylight?

3. If the sun were composed of glowing sodium vapors only, what colors should we have on the earth?

4. What difference in color is there between the electric light and gas-light, and what would be the effect of this difference on the colors of objects lit up by them?

5. Why will a strip of red glass cast a shadow on the blue of the spectrum and not on the red?

6. Will there be any difference in the effect on the spectrum if a piece of colored glass is held in the path of the ray after and before it passes through the prism?

7. If held as in the former case, which part of the spectrum will be seen on a piece of red glass?

8. A star gives a spectrum crossed by bright lines: what is its general constitution?

9. Certain parts of a comet give a spectrum of bright lines only: what does this indicate?

V.—POLARIZATION.

325. Polarization.—In water, while the wave moves horizontally, every particle vibrates vertically. In light the motion is also perpendicular to the direction of propagation of the ray, but at all angles to the vertical. Thus, if a beam be supposed to move in a direction perpendicular to this page, the vibrations of the ether are not only in the line *ab*, but also in all other lines, as *cd*, *ef*, etc. When all the vibrations are quenched except such as move in one direction, as *ab*, the light is said to be *polarized*.

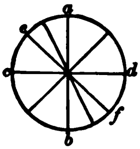


FIG. 208.—TRANSVERSE SECTION OF RAY OF LIGHT.

326. Polarization by Crystals.—This can be produced in various ways. Plates cut from crystals of tourmaline[1] parallel to the axis have the power to destroy all vibrations except such as are parallel to the axis. If we could suppose the crystal to be made up of bars which cut off all vibrations across them, we should have the effect. Hence a beam of light passing through such a plate is polarized. While there is no change in it visible to the eye, the polarization can be detected by means of another similar plate. If this is held so that its axis is parallel to that of the first, so that the "bars" of the two run in the same direction, the light will still pass through. If it is held at right angles, so that one destroys the rays which have passed through the other, no light will pass through. By

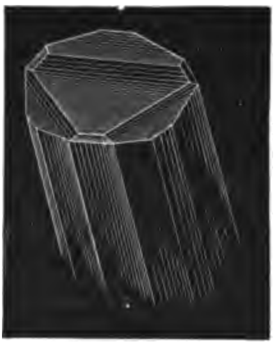


FIG. 209.—CRYSTAL OF TOURMALINE.

[1] Tourmaline is a semi-transparent mineral, crystallizing in long prisms. The axis runs parallel to its greatest length.

gradually revolving it from this latter position, more and more light can be seen. This is most readily experimented with by a pair of "tourmaline tongs," in one fork of which

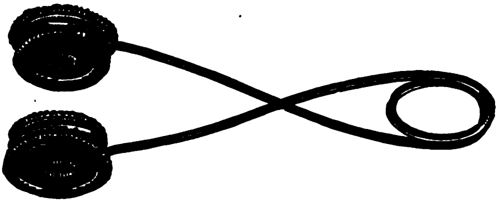


FIG. 210.—TOURMALINE TONGS.

the crystal can revolve. The first plate is called the *polarizer*, the second the *analyzer*.

327. Polarization by Reflection.—Light can also be polarized by reflection. If a ray be allowed to fall on a plate of glass at an angle of incidence which is about 57°, it will be polarized in the plane of reflection. That is, the vibrations will now be in lines parallel to the reflector, and others will be destroyed. If the reflected ray fall on a second plate at the same angle, it may be revolved so as to destroy the rays which the other keeps, or to keep them, and the polarization will be made evident. When placed in a position to reflect the light, as in Fig. 211, there will be no apparent change in brightness, but when the analyzer is revolved 90° the whole ray will be quenched. Such an instrument as this is one form of *polariscope*.

FIG. 211.—POLARISCOPE.

328. Polarization by Refraction.—There is still another

method of polarizing. If a crystal of Iceland spar be placed over a mark, the mark will appear double. The

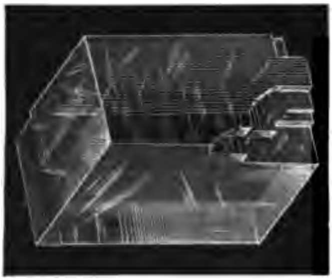


FIG. 212.—CRYSTAL OF ICELAND SPAR.

FIG. 213.—DOUBLE REFRACTION.

crystal has the power not only of separating the two vibrations, but of polarizing the parts, so that while one ray is polarized in one plane the other is in a plane perpendicular to this. If the direction of vibration of one ray be in the line of Fig. 214, the direction of the other will be shown in Fig. 215.

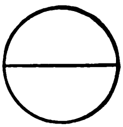


FIG. 214.

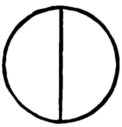


FIG. 215.

329. **Colors by Polarization.**—If a plate of selenium[1] or a piece of glass under compression be placed between the two plates of tourmaline of Fig. 210, a beautiful series of colored rings will be seen. If the analyzer be rotated through 90°, the colors will change to complementary. These colors are due to interference.

330. **Uses of the Polariscope.**—The polariscope is used in testing sugar, to determine the strength of a solution. An analyzer is also used to determine whether the light from comets, the solar atmosphere, and other heavenly appearances is polarized or not, thus determining whether it is light radiated directly by the body or sunlight reflected from it.

[1] An impure form of this is gypsum, or land-plaster.

VI.—OPTICAL INSTRUMENTS.

331. **Microscope.**—The simplest form of microscope is

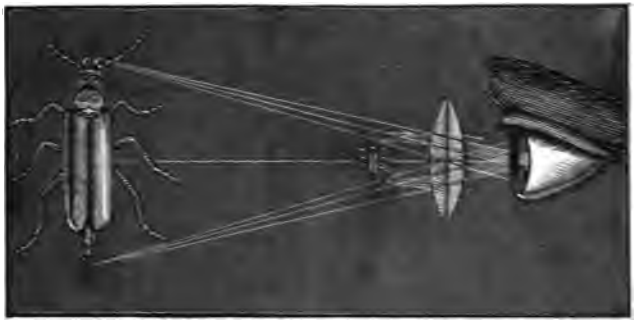


FIG. 216.—SIMPLE MICROSCOPE.

a double-convex lens, or magnifying-glass. Here we see an image of an object placed within its focal length magnified, because the rays are refracted so as to enter the eye as if they came from a larger object. The more convex the lens, the greater is the magnifying power. When very great power is required, it is, however, better for clearness of view to use two or more lenses of less curvature. The one next the object is the *object-glass*, or *objective;* the one next the eye is the *eye-piece*, or *ocular.*

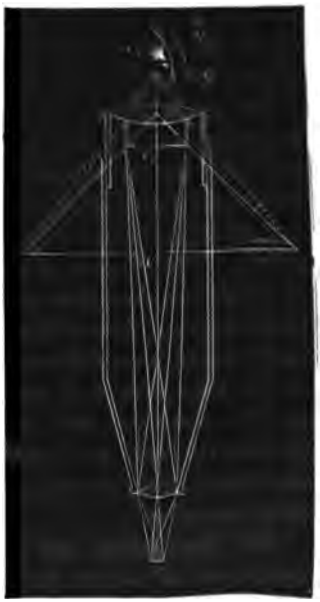


FIG. 217.—THE MICROSCOPE.

The object-glass makes a real and inverted image of the object. This image is viewed by the eye-piece as if it were an object. It does not reinvert the image;

hence, with respect to the original object, the final image is inverted. Fig. 217 gives the course of rays through a microscope.

332. **Telescope.**—In a telescope the principle is the same.

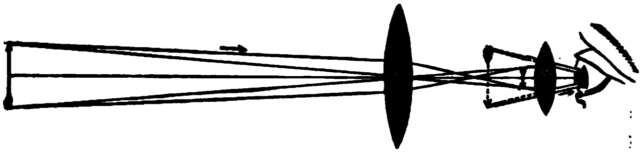


FIG. 218.—PRINCIPLE OF THE REFRACTING TELESCOPE.

An image of a distant object is formed at the focal length of the objective, and is magnified by the eye-piece.

In the microscope the image of the object is greater than the object, and in the telescope it is less. In the former the image increases as the focal length of the objective decreases; that is, as the curvature becomes greater. In the latter, for distant objects, the image increases as the focal length increases; that is, as the lens is made flatter.

333. **Object-Glass.**—To make a good objective, it has to be corrected not only for spherical aberration (page 187), but also for the *dispersion* produced by the glass. This would have the effect of producing spectra and surrounding all objects with fringes of color. This is *chromatic aberration.* The method of making the correction is as follows. A double-convex lens of crown glass is combined with a plano-concave lens of flint glass. These glasses, being differently made, have different internal structure. The tendency of the flint glass is to neutralize the dispersive effects of the crown glass, but not its refractive effects, except in part. Hence the rays are brought to a focus, and the colors are not much seen; though it is impossible to make the correction complete.

334. **Refracting and Reflecting Telescopes.**—Such telescopes as the above are called *refracting telescopes.* Sometimes the first image is made by a concave mirror, and is

then viewed by an eye-piece, as in the case of the other. These are *reflecting telescopes.* One form of them is seen in Fig. 219.

Here also the first image is inverted. In case it is desired to see things erect, as in a terrestrial telescope or a

FIG. 219.—PRINCIPLE OF THE REFLECTING TELESCOPE.

spy-glass, another lens is added, to reinvert the image. Two lenses are found to answer better than one for the eye-piece. Also in a terrestrial glass four lenses are used instead of two.

335. **Opera-Glasses.**—The first telescope ever made—Galileo's—was a combination of a convex objective with a con-

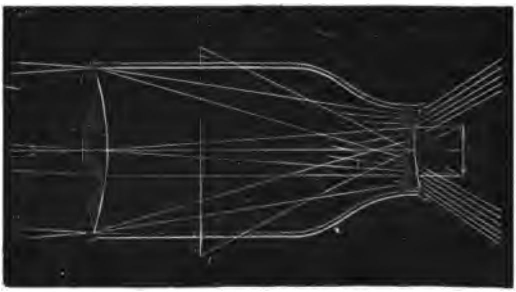


FIG. 220.—PRINCIPLE OF THE OPERA-GLASS.

cave eye-piece. The latter was placed so as to intercept the rays before they reached the focus, so that no image was formed by the objective. An apparent image was

formed by the eye-piece, which was erect. This telescope has a large field of view, but small magnifying power, and is used in opera-glasses. Each tube is such a telescope.

336. **Cause of Solidity.**—Bodies appear solid to us because we see them with both eyes. With one eye we see a little around one side, and with the other a little around the other. These two pictures give the appearance of solidity.

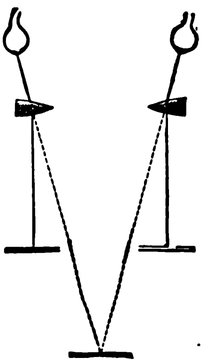


Fig. 221.—Principle of the Stereoscope.

Experiment 119.—Look with one eye at objects of which you do not know the shape, and notice how flat they appear. Notice, also, how difficult it is to judge of distance with one eye shut, by attempting to place the finger on the object. With one eye shut, endeavor to place against each other two pencil-points at arms'-length.

337. **Stereoscope.**—The stereoscope is constructed on this principle. Two pictures of an object are taken from slightly-different positions. These are placed so that the light from them after passing through glasses appears to throw them into the same position. The points of difference in the two

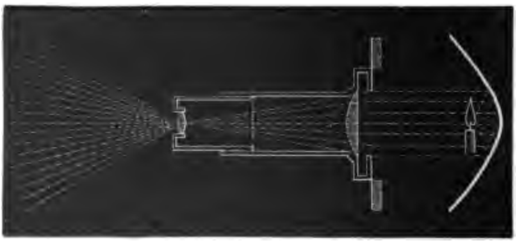


Fig. 222.—Principle of the Projecting Lantern.

pictures are brought out and blended together, giving the effect of solidity.

338. **Projecting Lantern.**—A projecting lantern is often used for lecture and educational purposes for throwing pictures on a screen in front of the audience. A light, usually

composed of a burning stream of house-gas and oxygen playing upon a piece of quick-lime, is contained in an opaque box. In the front part of this box are one or two double-convex lenses, which bring the rays to a focus. In front of this lens is placed the picture to be exhibited. An image of this, real and inverted, is then thrown on the screen by another combination of lenses. The size of the image depends on the distance of the screen from the lantern.

339. **The Camera.**—The camera used by photographers is a dark chamber with a convex lens in front and a screen at the back. The lens produces on the screen an image of the objects in front of it. The screen is ground glass, semi-transparent, so that the image can be seen from behind. When this image is made clear by careful focusing, the lens is covered, the sensitive plate is put in, and exposed by uncovering the lens.

340. **The Eye.**—The eye is an instrument in optical principles nearly the same as the camera. It consists of a ball surrounded with a strong, firm coat, the *sclerotic coat*,—the "white of the eye,"—except a little space in front, where there is a transparent coat, the *cornea*. Inside the sclerotic is the *choroid coat*, of dark color, to quench the scattering rays; this is seen through the *pupil* of the eye. Inside of this, again, is the *retina*. Back of the cornea is a chamber filled with a transparent liquid, the *aqueous humor*. Behind this, again, is the *iris*, a mass of radiating fibres, which by their expansion and contraction change the size of the hole in the centre, the *pupil*, and also give the color to the eye. Back of this is the crystalline lens, a double-convex lens of cartilage, held in place by muscles. Back of the crystalline lens, and filling the main body of the eye, is the *vitreous humor*. The rays of light from external objects are made slightly more convergent by the cornea, and are brought to a focus on the retina by the crystalline lens, forming a real and inverted image there. The impression of this image

conveyed to the brain by the optic nerve gives the sensation of sight. Each eye forms its own image, as in the

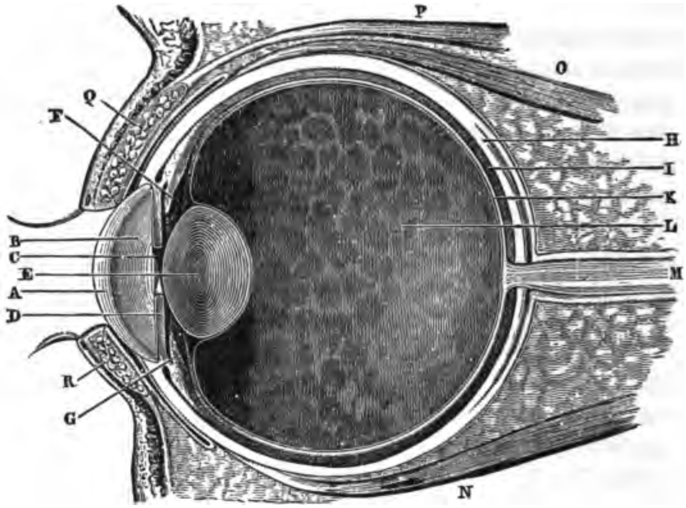


FIG. 223.—THE HUMAN EYE.

FIG. 223.—THE HUMAN EYE. A, cornea; B, aqueous humor; C, pupil; D, iris; E, crystalline lens; H, sclerotic coat; I, choroid coat; K, retina; L, vitreous humor; M, optic nerve; N, O, P, muscles.

stereoscope: these images are slightly different, and their blending gives the idea of solidity.

341. **Defects in the Eye.**—When the image is clear and distinct on the retina, the impression is clear and distinct. If, through any error of curvature of the cornea or crystalline lens, the image is not made exactly on the retina, sight is not perfect. If the image is formed in front of the retina, the person is *short-sighted;* if it is intercepted by the retina before reaching a focus, the person is *long-sighted.* It is the case of a camera out of focus. The unconscious endeavor to focus the eye in such cases produces straining of the muscles, pain, and disease. This is corrected by the use of glasses, either concave or convex. If the person is long-sighted, a convex lens is put in the spectacles, to assist

the crystalline lens in bringing the object to a focus on the retina; if short-sighted, a concave lens, to overcome the effect of the too great convexity of the crystalline.

342. **Focus of the Eye.**—As rays from a near object do not come in so nearly parallel as if the object were distant, the muscles have the power to change the curvature of the crystalline lens to suit the differing distances. This is done without effort on our part, and, unless continued so long as to tire the muscles, without any inconvenience. The eye can immediately turn from reading a book to look at the distant horizon without effort or pain, though it involves considerable changes in the curvature of the lens.

Experiment 120.—Procure an eye of an ox or other animal, freeze it, and cut it into two from front to back with a razor. Notice the various parts described above.

343. **Persistence of Impressions.**—An impression on the retina is not immediately effaced, but after the object creating it is removed, it will still remain a few seconds. If a stick with a glowing coal on it be whirled around, a whole circle of light can be seen. Experiment 111 is also explained by this. The different colors are mixed in the eye, and white is produced.

344. **Inversion of the Image.**—The image is inverted on the retina by the convex crystalline lens, but the impression is rearranged in the optic nerve or in the brain. An image is seen in both eyes, but these are combined into one, except in the case of an object too close for distinct vision, or in other abnormal cases.

345. **Blind Spot.**—The part of the retina immediately over the end of the optic nerve does not transmit its impressions to the brain. This is the "blind spot" of the eye. Its presence may be shown as follows.

Experiment 121.—Make three heavy circles, as below. Close the

left eye, and hold the left spot in front of the right eye; look at it

intently. By moving the paper slightly right and left a place can be found where the left spot will be visible and not the centre one. Its image falls on the blind spot.

General Exercises.—1. Suppose a coin an inch in diameter to be held up before a wall parallel to it; let the distance of the coin from the source of light be 15 inches, and that of the wall from the source 5 feet: show that the area of the shadow is 16 times that of the coin.

2. Show that if light takes three years to pass from a star to the earth, that star is nearly 200,000 times more distant from the earth than the sun is.

3. If the weight of a molecule of light amounted to but one grain, show that its momentum would be about equal to that of a cannon-ball weighing 150 pounds and moving with the velocity of 1000 feet in a second.

4. Show at what angle a ray must be incident on a plane reflecting surface in order that the reflected ray may make a right angle with the incident ray. *Ans.* 45°.

5. Find the angle between two plane reflectors so that a ray originally parallel to one of them may, after two reflections, be parallel to the other. *Ans.* 60°.

6. A man stands upright before a plane vertical reflector, and observes that he cannot see the image of his head or of his feet: show that if he goes nearer to the reflector or farther from it he can still see only the same portion of his image as before.

7. A man stands before a looking-glass of his own height: show that he can see his whole image, and determine how much of the looking-glass is concerned in the formation of the image.

8. The sun is 30 degrees above the horizon, and his image is seen in a tranquil pool: determine in this case the angle of incidence and reflection.

9. A man stands before a looking-glass with one eye shut, and covers its place on the glass with a wafer: show that the same wafer will hide the other eye as soon as it is shut and the first is opened.

10. A small object is placed half-way between the centre and the principal focus of a concave reflector: draw the image, and show in what proportion it is to the object.

11. State what would be the appearance of a man standing on the brink of a lake to an eye under the water.

12. The rays of the sun are received on a large converging lens, the focus being rendered visible by the dust floating in the air; a screen placed a little in front of the focus shows a white circle surrounded by a red fringe, and placed a little behind the focus shows a white circle surrounded by a blue fringe: explain this.

13. A window-bar is viewed through a prism, the edge of which is parallel to the bar: show that the side of the bar which is nearer to the edge of the prism is fringed with red and orange, and the other side with violet and blue.

CHAPTER VII.

HEAT.

346. **What is Heat?**—Heat, like light, consists of waves of ether. The waves of heat cannot be seen by the eye; they can be felt by the nerves of sensation, which are scattered over the whole surface of the body.

Heat is, then, a mode of motion.[1] When a body is heated its particles are set in vibration. This vibration is then communicated to the ether which is in contact with them, and so is conveyed to the senses. As the temperature is raised, the vibrations become more and more rapid, till after a while they have such rapidity that they are capable of being perceived by the eye, and the body is seen to glow.

347. **Theories of Heat.**—There was an old theory that heat was caused by the passage of particles of matter from the heated body. But this seems to be now disproved. The present theory of heat is called the *undulatory theory.*

348. **Sources of Heat.**—The sources of heat are in general the same as the sources of light. The great reservoir is the sun. It is constantly giving it out to the earth: the earth uses some of it up, and some it radiates again into space. An immense amount of heat is received even in the frigid regions from the sun. Were it not for this, the temperature of the whole earth would be far below zero continually.

---

[1] Prof. Tyndall has written a book called "Heat a Mode of Motion." This is an excellent treatise on the subject, and will give to students a valuable lesson in the careful habits which are necessary to a scientific investigator.

349. Chemical Action a Source of Heat.—Chemical action is another source of heat.

Experiment 122.—Mix some strong sulphuric acid and water slowly together, stirring the mixture. They combine, and the vessel is heated. A thermometer will show the rise in temperature.[1]

The heat from combustion is from this source. There is a chemical union between the oxygen of the air and the carbon and hydrogen of the combustible. A certain amount of heat is necessary to start this action, but when started it keeps itself going by the heat which it generates.

Experiment 123.—Put some "quick-lime" in water; apply the thermometer to the water before and after. There is here chemical union between the lime and the water, and "slaked lime" is formed.

350. Stoppage of Motion a Source of Heat.—The stoppage of motion is a great source of heat.

Experiment 124.—Lay a nail on an anvil, and strike it two or three sharp blows with a hammer. Then quickly touch the nail to a little piece of phosphorus, or, if this is not to be had, give it more strokes and touch it to the head of a match. The phosphorus or the match will take fire.

We say the *motion is converted into heat.* This means that the motion of the hammer is changed into the vibratory motion of the particles of the nail, which in turn communicates itself to the particles of the phosphorus. It is an illustration of the *correlation of forces.*

351. Illustrations of the Conversion of Motion into Heat.—There are many illustrations of the conversion of motion into heat. Meteors, or "shooting-stars," are little stones which enter our atmosphere with great velocity. They strike so many particles of air, and so much of their motion is stopped, that they become intensely hot, and finally burn up, giving out the light by which we see them. All friction is accompanied by heat, for a similar reason. It is the stoppage of motion. Friction-matches, the heating of

[1] For this and similar experiments a thermometer should be procured without a frame, and with the markings on the tube.

axles, the Indian habit of rubbing two sticks together or of striking flints to light a fire, rubbing the hands to warm them, are illustrations.

352. It is believed that the heat of the sun is partly supported by the fall of bodies into it and the conversion of their motion into heat. As we know that the sun is continually expending its energies in all directions into space, we must explain in some way its sustenance, and the heat generated by the fall of bodies from some distance away would be many times greater than that which would be produced by their combustion were they composed of solid coal.[1]

353. **Mechanical Equivalent of Heat.**—A given amount of motion stopped will always produce the same amount of heat. The amount of motion in a body depends on two things,—the mass and the velocity,—and is measured in foot-pounds. To raise one pound of water through one degree Fahrenheit requires 772 foot-pounds of motion stopped. If a pound-weight could fall into a pound of water from a height of 772 feet, and all the heat resulting could be collected in the water, its temperature would be raised one degree Fahrenheit.

This number 772 is called the *mechanical equivalent of heat*, and was determined by Joule[1] in a number of ways, one of which was the following. He had a box of water in which were a number of paddles which churned the water. These paddles were turned by a weight falling. The weight being known, and the space through which it fell, also the difference of temperature of the water at the beginning and at the end of the fall, the amount of fall necessary to produce an increase of 1° was easily calculated. Thus, a 100-pound weight falling through 20 feet would perform 2000 units of work. If this raised the temperature

[1] See Sharpless and Philips's "Astronomy," Art. 47.

[2] James P. Joule (jool), an English physicist, 1818–.

of one pound of water 2.59°, then to raise it 1° there would be $2000 \div 2.59 = 772.2$ units of work expended.

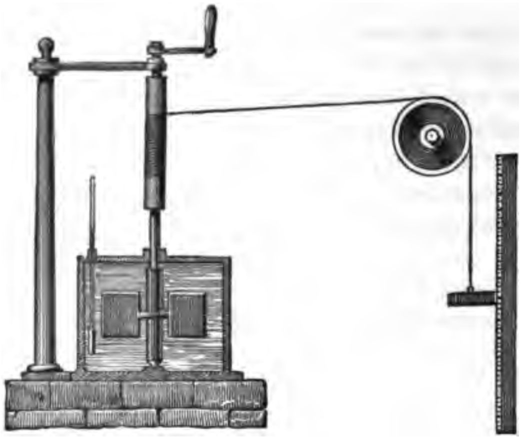


FIG. 224.—JOULE'S MACHINE.

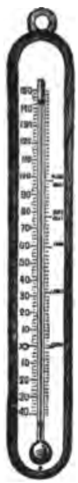


FIG. 225.—THERMOMETER.

354. Conservation of Energy.—If now this heat could all be utilized in an engine, it could just lift the weight to the point from which it fell. We have another illustration of the "conservation of energy." The mechanical motion is destroyed, but an equivalent in molecular motion (heat) is produced. A certain amount of mechanical motion always produces the same amount of heat, and if this could all be collected it would in turn reproduce the mechanical motion. The energy is not lost, but is converted into another form. Heat is converted into mechanical motion in locomotives. This goes again into heat in the friction of the bearings of the different axles of the train, of the wheels against the track, and of the train against the air.

355. Thermometers.—Temperature is measured by thermometers. The most common thermometer is the

mercury thermometer, and it depends upon the principle that heat expands the mercury in a tube and cold causes it to contract. It consists of a bulb with a tube attached. The bulb and part of the tube are filled with mercury, and the remainder contains no air, but only a little vapor of mercury. To construct a thermometer the mercury is heated in the bulb, and when the tube is full of vapor it is sealed up at the upper end. Then in cooling most of the vapor condenses and leaves nearly a vacuum in the upper part of the tube.

FIG. 226.—TO FIND THE FREEZING-POINT OF A THERMOMETER.

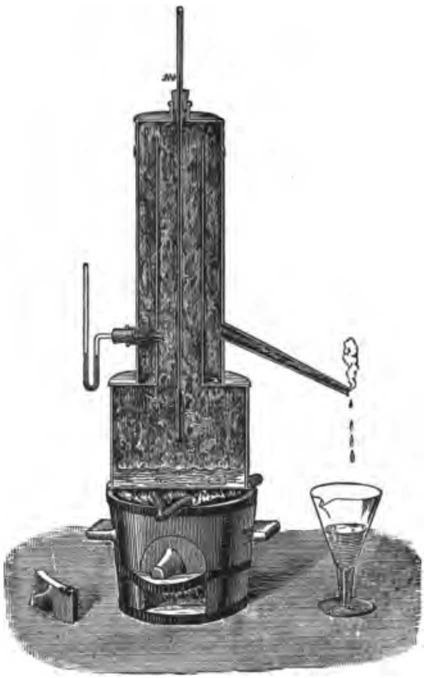


FIG. 227.—TO FIND THE BOILING-POINT OF A THERMOMETER.

356. **Freezing-Point and Boiling-Point.**—There are several ways of graduating thermometers, but in all there are

two points which must be determined. These are the freezing-point of water and the boiling-point of water.

To determine the first, the bulb is kept in a mass of chopped ice or snow till the mercury settles at a definite place. This place is then marked.

To determine the boiling-point, the bulb is placed in boiling water, from which the steam is allowed to pass freely and to envelop the tube. The point at which the mercury settles is then also marked.

357. **Graduation.**—We have now two marks, and it is necessary to graduate the thermometer between them. There are two common methods of doing this.

358. **Centigrade Thermometers.**—The first is the Centigrade method, used in France, and by scientific people everywhere. The freezing-point is marked 0°, and the boiling-point 100°, and the space between is divided into 100 equal divisions. Divisions of the same size are then continued above 100° and below 0° as far as necessary.

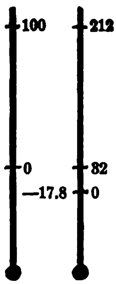


FIG. 228.—CENTIGRADE AND FAHRENHEIT THERMOMETERS.

359. **Fahrenheit Thermometers.**—The other is the Fahrenheit method, used by people in general in England and the United States. The freezing-point is marked 32°, and the boiling-point 212°, and the space between is divided into 180 equal divisions, which are continued up and down. Both methods will be used in this treatise, the addition of the letter C. or F. stating which.

As 100° C. are equivalent to 180° F., 5° C. are equivalent to 9° F.; hence any number of degrees of one scale can be reduced to its corresponding number of the other.

Exercises.—1. To what marking on F. scale does 40° C. correspond?

$$\begin{aligned} \text{Since } 5^\circ \text{ C.} &= 9^\circ \text{ F.,} \\ 1^\circ \text{ C.} &= \tfrac{9}{5}^\circ \text{ F.,} \\ \text{and } 40^\circ \text{ C.} &= 72^\circ \text{ F.} \end{aligned}$$

This gives the number of F. degrees above freezing-point, which is 32° above zero. Then the reading of the F. scale would be 104°.

2. To what marking on C. scale does 122° F. correspond? *Ans.* 50°.

3. To what marking on F. scale does 10° C. correspond? *Ans.* +50°.

4. To what marking on C. scale does —40° F. correspond? *Ans.* —40°.

5. How many units of work are required to raise 1 pound of water through 1° C.? *Ans.* About 1390.

360. **Unit of Heat.**—It is convenient to have some unit by which to measure the amount of sensible heat in a body. The unit adopted is *the amount of heat required to raise the temperature of one pound of water at* 32° *through one degree.*

361. **Specific Heat.**—If instead of taking a pound of water we take a pound of mercury and expose it to the same heat, its temperature will rise more than that of water. More of the heat given to the water is employed in keeping the molecules in vibration than in the case of the mercury, so that it does not show itself by a thermometer. All known substances except hydrogen will rise in temperature farther than water by the application of the same amount of heat. *The specific heat of a substance is the amount of heat necessary to raise one pound of it through one degree, the specific heat of water being* 1.

One way of determining the specific heat of a substance is by the method of mixtures.

Experiment 125.—Mix together one pound of water at 80° and one pound at 50°. The mixture will be at 65°. The former loses as much as the latter gains.

Experiment 126.—Mix one pound of water at 80° with one pound of mercury at 50°. The mixture will be at 79°. The water has lost 1°, and that has raised the mercury through 29°. The specific heat of mercury is therefore $\frac{1}{29}$.

362. **Heat produces Expansion.**—The general effect of heat is to expand bodies. An iron ball that will just pass through a ring when cold, is too large when hot. An iron rod will measure a little longer when heated. The rails of a track laid in summer will be separated in winter.

The expansion is accomplished by the separation of the

molecules, and the separation is caused by their rapid vibration. This requires more room, and overcomes to some extent the force of cohesion. The force of separation is so

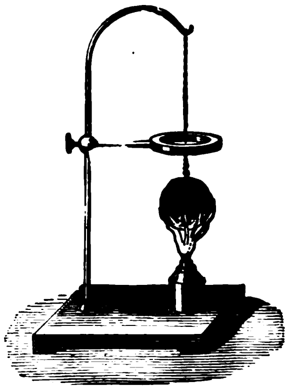


FIG. 229.—EXPANSION OF SOLIDS BY HEAT.

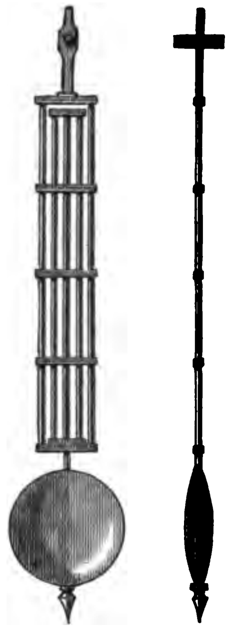


FIG. 230.—EXPANSION BY HEAT.—GRIDIRON PENDULUM.

great that it is generally useless to try to counteract it. In iron buildings and bridges arrangements are made so that the pieces can be allowed to expand without injury.

363. **Melting and Evaporation by Heat.**—As the heat is increased, the particles are more and more agitated and dispersed, and the force of cohesion becomes less and less, until finally the body changes from a solid to a liquid. If heat is still applied to it, the molecules are farther separated, until they reach such a distance apart that no cohesive force acts between them, and the liquid becomes a gas.

Melting and evaporation, then, must be considered as the shaking apart of the molecules by the vibratory motion communicated to them, which vibratory motion is heat.

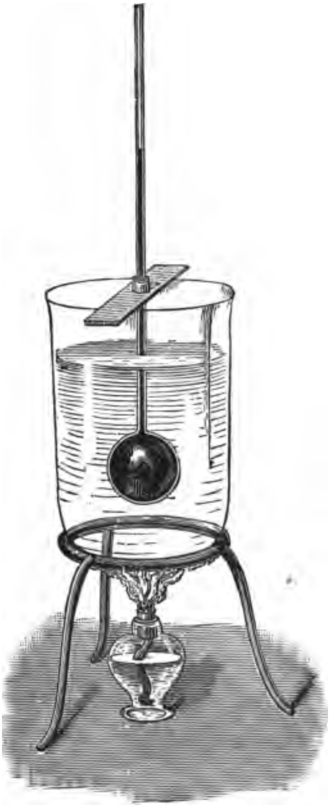


FIG. 231.—EXPANSION OF LIQUIDS BY HEAT.

FIG. 232.—EXPANSION OF AIR.

364. **Expansion of Liquids.**—The expansion of liquids can be readily seen by

Experiment 127.—Partly fill with colored liquid a glass tube with a bulb. Immerse the bulb in water, and apply heat gently. The colored liquid will rise in the tube. Thermometers are based on the principle of the expansion of liquids by heat.

365. **Expansion of Gases.**—The expansion of gases can be seen by the following:

Experiment 128.—Heat a flask filled with air, and conduct a tube into a vessel of water. The expanded air will be driven out of the tube, and will bubble up through the water.

Experiment 129.—Tie up a bladder or a toy balloon partly filled with air. Heat it, and the balloon will expand.

In Experiment 128 it is evident that the air remaining in the flask will weigh less after being heated than did the original, for there are fewer particles.

366. **Law of Expansion of Gases.**—There does not seem to be any general law which can be said to govern the cases of expansion of solids and liquids, since they are so diverse in their qualities. But a true gas (not a vapor) will expand according to a certain law, whatever its composition. *If kept under a constant pressure as it expands, it will increase* $\frac{1}{273}$ *of its volume at* 0° *for every Centigrade degree of heat given it.*

To illustrate this, suppose p to be a piston fitting closely in a tube ab, but moving up and down without friction, and suppose the portion pb below the piston to be filled with gas at a temperature of 0° C. If the temperature be raised to 1°, the gas will expand $\frac{1}{273}$ of its volume, and will lift the piston; if raised to 2°, it will expand $\frac{2}{273}$ of its original volume; and so on. If raised to 273°, it will have just double its original volume.

Fig. 233.

We can also carry the process the other way. If 1° of heat be taken from the gas, the resulting volume will be $\frac{272}{273}$ of the original; if 2°, $\frac{271}{273}$; and so on down. In theory, when the gas is cooled to —273° it would have no volume at all. But practically it becomes a solid long before it reaches this temperature, and the law does not apply to solids. This number, —273° Centigrade, is called the *absolute zero of temperature.*

What would be the absolute zero on F. scale?

367. **Relation between Heat and Volume.**—When a body is heated, some of the heat goes to expand it, so that the temperature is not so great as it would otherwise be. If the piston in Fig. 233 were held down so that the gas could not expand, the same amount of heat applied to it would raise its temperature higher. In expanding, part of the heat is used up in doing the work of separating the molecules. This heat is consumed continuously in keeping the molecules apart, and any abstraction of heat will allow them to come together again. Hence cold produces contraction. Cooling is the loss of vibratory motion, and as the motion ceases, the molecules approach one another.

Now, if the expansion is produced by a force, without the application of any external heat, cold is produced. For part of the heat previously in the body is now consumed in maintaining the separation of the molecules. The sudden stretching of a wire lowers its temperature.[1]

368. **Heat and Fusion.**—When heat is applied to a solid body so as to raise its temperature to the point of fusion or melting, the addition of more heat will not further raise the temperature till the body is completely melted. The heat does the work of driving the molecules apart, and so changing it from solid to liquid. A certain amount of heat is consumed in maintaining the liquid form.

Experiment 130.—Place a piece of ice in a vessel over a slow fire. As the ice melts, keep it well stirred, and frequently apply a thermometer. It will indicate the freezing-point until all the ice is melted.

Although much heat has gone into the ice, it has been destroyed as sensible heat, and is employed in keeping the molecules at such a distance from one another as to make a liquid. This energy, which does not show itself by a thermometer, is called *latent heat*. It requires 80 units of heat to melt ice, or as much as would raise the same weight of

[1] India-rubber seems to be an exception to both laws. When stretched, heat is produced, and the application of heat contracts instead of expanding it.

water through about 80° C. of temperature. When the ice freezes, the same amount of heat is given out.

Melting, then, implies the using up of heat. As this heat comes from external sources, its effect is to reduce their temperature. Freezing, on the contrary, liberates heat and raises the temperature of surrounding objects. Melting causes cold, and freezing causes heat.

Experiment 131.—Mix some chopped ice with salt, and stir well together, and keep a thermometer in the mixture. It will indicate a temperature much below the freezing-point. The salt makes the ice melt, and so causes cold. This is the common freezing mixture used by ice-cream-makers.

Experiment 132.—Pulverize some nitrate of ammonium in a thin glass vessel, add water, and stir. As the salt dissolves, insert the bulb of a thermometer. The mercury will rapidly fall. Place the vessel on a wet board. It will freeze to it.

Here the rapid solution of the salt in water abstracted heat from the vessel, from the thermometer, and from the board. Hence not only fusion, but solution, causes cold.

Define fusion and solution.

369. **Heat and Evaporation.**—Similar effects are seen in the passage from the liquid to the gaseous state. Heat is required to keep up the gaseous condition of a body: hence evaporation takes heat from surrounding objects and causes cold, and condensation liberates it and raises temperature.

Experiment 133.—Pour a little ether in the palm of the hand. As it rapidly evaporates, considerable cold is felt. Dip a thermometer in ether and quickly remove it. The ether which adheres will evaporate and take heat from the mercury in the bulb.

370. **Freezing in Red-Hot Vessels.**—Sulphurous acid—the gas formed when sulphur is burned in air—is capable of being made liquid by passing it through a tube immersed in a freezing mixture of ice and salt. If a crucible be heated red-hot, a little water put in it, and immediately the liquid sulphurous acid poured on it, so great a degree of cold will be produced by the sudden vaporization of the acid that the water will be frozen in the red-hot crucible.

371. **Solidification of Gases.**—If a gas be condensed by

great cold and pressure, and then suddenly be allowed to expand by passing out through a fine tube, the great expansion and evaporation will cause such cold that the gas will be liquefied, and in some cases solidified. Hydrogen, the lightest of all gases, has been made solid by this method, and been heard to rattle on the floor like minute hailstones.

372. **Cryophorus.**—A cryophorus is an instrument consisting of two glass bulbs connected as in Fig. 234. One of these is partly filled with water, and the rest of the apparatus is made as nearly as possible a vacuum. This is soon filled with vapor of water, which passes off under the low pressure. If the *other* bulb is placed in a freezing mixture of ice and salt, the vapor is condensed, and evaporation goes on so rapidly from the water that it finally freezes.

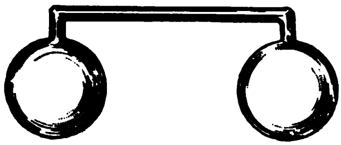


FIG. 234.—CRYOPHORUS.

373. **Artificial Ice.**—In India, ice is made by putting water into pots of porous earthenware. The water evaporates from the outside of these so as to freeze the water on the inside. Artificial ice is produced in warm countries on a large scale by passing liquid ammonia through pipes which line the bottom and sides of a vessel of water. The liquid is quickly converted into a gas, and this takes so much heat from the water that it is frozen.

Experiment 134.—Heat some water, having the bulb of a thermometer in it during the operation. The mercury will gradually rise till it reaches the boiling-point; after which, if the steam is not confined, it will not indicate any higher temperature till the water is boiled away.

374. **Heat and Evaporation.**—In this experiment the heat applied after the water commenced to boil is all expended in changing the liquid to a gaseous form, and becomes *latent* in the gas. To change water into vapor requires about 537 times as much heat as would raise the same amount through one degree of temperature,—in other words, 537

units of heat. This number 537 is called the latent heat of steam, as 80 (see Par. 368) is the latent heat of water. They represent the number of degrees of heat stored up and kept in constant use in maintaining the condition of the body, and which will not show itself by a thermometer.

375. **Heat expended in Fusion and Evaporation.**—To show the meaning of these figures, let us suppose a mass of ice at a temperature of —10° C., and let it be heated from a source which gives it 1° a minute. In 10 minutes it will be brought to 0°. In 80 minutes more it will be all melted, but it will still be at 0°. In 100 minutes more it will be raised to a temperature of 100°, and will begin to boil. In 537 minutes more it will all be converted into vapor at a temperature of 100°. This vapor can then be increased in temperature by the application of heat.

Exercises.—1. Why does moist clay contract when heated?

2. Why do telegraph-wires hang down more in summer than in winter?

3. Why does a wheelwright put the tire on the wheel hot?

4. Will sugar placed in coffee cool it more than the same amount of sand at the same temperature? why?

376. **Expansion by Freezing.**—The general effect of cold is to contract. There are exceptions to this in the case of water under certain circumstances, and of a few other substances. When water is reduced in temperature it contracts in volume till it reaches the temperature of 39° F. or 4° C., after which it begins to expand. This expansion amounts to about $\frac{1}{14}$ of its original bulk, and shows itself in bursting vessels in which it is contained. Heavy iron shells can be thus burst. Fig. 235 represents the effects of this expansion. A large shell was filled with water and the hole tightly stopped by a wooden plug. When it froze, the plug was forced out with great velocity and a cylinder of ice eight inches long issued from the hole. At another time the shell split in two, and a sheet of ice was forced out.

This lightness of ice causes it to float on water. If it

continued to contract as it cooled, it would sink, and all of it would be at the bottom of the ponds.

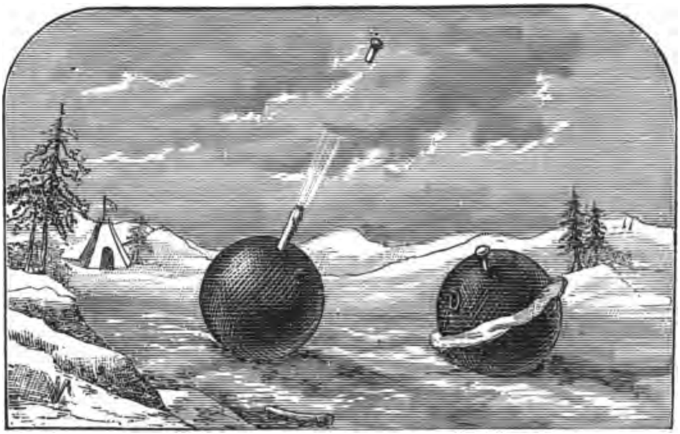


FIG. 235.—EFFECTS OF FREEZING.

377. **Freezing.**—Freezing is the formation of crystals. They begin to form around the edge of the pond or around some object floating in the water, and add one to another till the whole surface is frozen. The process can be watched by the following method.

Experiment 135.—Wet a clear piece of glass with a solution of sulphate of copper or chloride of ammonium, and hold it between you and the light. In a little while, as the water dries, the crystals will begin to shoot out in various directions over the glass. The effect is much improved if the plate is placed in a projecting lantern and the formation of crystals shown on the screen.

378. **Melting.**—Melting is the reverse process from freezing. When the temperature is raised above the freezing-point the crystals gradually dissolve into water. This goes on all through the mass, and the ice becomes rotten before it disappears.

379. **Evaporation and Boiling.**—Evaporation goes on at all temperatures. Ice is converted into vapor without passing through the intermediate stage of liquids. Clothes hung out in cold weather will become dry while the tem-

perature is all the time below the freezing-point. But the process goes on the more rapidly the higher the temperature. As water is slowly heated, steam passes away from its surface with greater rapidity until, when a certain temperature is reached, steam begins to form all through its mass. This, being lighter than water, is forced up through it to the top. This is *boiling*. The heat being applied at the bottom, that portion is most heated, and steam is there formed most vigorously. Not only the steam but also the heated water, being expanded, rises, and the other water takes its place, to be in turn heated. Thus there is a constant circulation.

Experiment 136.—Add a little chalk-dust from the blackboard to water in a glass flask, and heat it; watch the circulation of the water by the aid of the particles of dust.

In such experiments wipe the flask dry on the outside, and apply the heat gradually at first.

FIG. 236.—BOILING AS AN EFFECT OF REDUCED PRESSURE.

380. **Relation of Boiling-Point and Pressure.**—The boiling-point varies with the pressure. By exhausting the air over water it can be made to boil at a much lower temperature. Whenever the tension of the vapor equals the outside pressure, boiling begins.

Experiment 137.—Boil some water in a flask, and remove the lamp. When the boiling has ceased, cork the flask, invert it, and pour some cold water on its base. The boiling will begin again. The cold water condensed the vapor and reduced the pressure.

This principle is used in the manufacture of certain dye-stuffs, and in sugar-refining, where it is desirable to evaporate the water at a low temperature. A partial vacuum is formed in the boiler, and the steam, as fast as it passes off, is condensed by a falling spray of water.

As we ascend a mountain the boiling-point lowers. An approximation to the height may be formed in this way: Roughly, the height in feet will be found by multiplying 600 by the number of degrees below 212° F. at which water boils.

Questions.—1. On a certain elevation water is found to boil at 200° F.: what is its height? $12 \times 600 = 7200$ feet, nearly.

2. A mass of gas at 60° C. and under a pressure of 30 inches measures 100 cubic inches: what will be its volume at 40° C. and under a pressure of 28 inches?

Solution.—At 60° its volume will be $\frac{60}{273}$ greater than at 0°; at 40°, $\frac{40}{273}$ greater. Now, 100 cubic inches $= 1\frac{60}{273}$, or $\frac{333}{273}$, its volume at 0°. Hence

$$\text{Volume at } 0° = \tfrac{273}{333} \times 100 = 81.9.$$
$$\text{Volume at } 40° = \tfrac{313}{273} \text{ of } 81.9 = 93.8.$$

This is the volume under 30 inches pressure. Under 28 inches, by Mariotte's law, the whole will be $\frac{30}{28}$ of $93.8 = 100.5$ cubic inches.

3. A mass of gas at 0° C. occupies a litre: what will be its volume at 546° C. under the same pressure? *Ans.* 3 litres.

381. **Steam.**—Steam occupies about 1700 times as much space as the water which produces it. In other words, a cubic inch of water will make about a cubic foot of steam.

382. **Distillation.**—Condensation is the reverse of evaporation. It takes place whenever the vapor is reduced in temperature below the boiling-point of the liquid. This is what causes the formation of dew, clouds, and rain.[1] Distillation is the condensation of certain portions of a liquid which separate from contained solids, or pass off at a lower temperature than the remainder. In this way water can be separated from the impurities which it contains, and alcohol from the water with which it is mixed.

The instrument by which this is effected is a *still*. A

[1] This subject will be found more fully treated in the chapter on meteorology.

retort containing the liquid is heated and the vapor passed over into a "worm," which is kept cool by being immersed

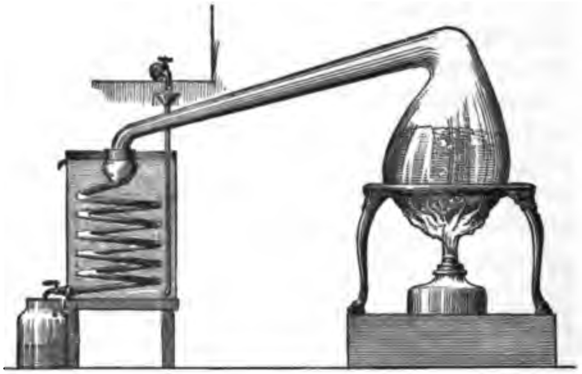


FIG. 237.—STILL.

in cold water. Here the vapor is condensed and runs out at the lower end, while the solid impurities or the less volatile liquids remain in the retort.

Experiment 138.—Drop a little water on a piece of iron heated to about 150° C. It will form into a drop and dance about the surface, and not evaporate very rapidly. Allow the plate to cool. At a certain temperature the drop will break, spread over the iron, and almost immediately change to vapor.

In this case the great heat of the plate causes such a down-rush of steam that the drop rests on a cushion of steam, and not on the plate. This fact can be readily seen by

Experiment 139.—Place a candle in the right position, and you can see light between the drop and the plate.

TRANSMISSION OF HEAT.

383. **Transmission of Heat.**—Heat travels through ether just as light does. The vibrations of the heated body are communicated to the particles of ether in contact with them, these act on the next, and so the motion is extended. The heat- and the light-rays are, partly at least, exactly the same rays. Some rays give us sensations of both light

and heat, some of heat only; hence heat- and light-rays, being largely the same, follow the same laws. Heat, like light, decreases as the square of the distance increases

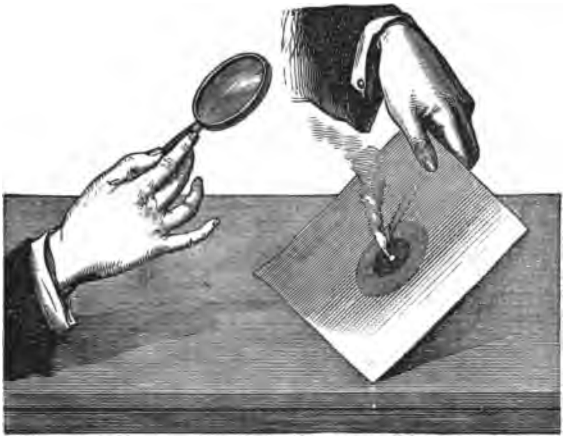


FIG. 238.—REFRACTION OF HEAT BY A BURNING-GLASS.

(see Par. 257); it is refracted in accordance with the "law of sines" (see Par. 280), and it is reflected, making the angle of incidence equal to the angle of reflection.

384. **Luminous and Dark Heat.**—The laws are the same whether the heat comes from a glowing body, like a candle or the sun, or from a dark body, as a vessel filled with hot water. In the one case we have *luminous heat*, and in the other we have *dark heat.*

385. **Radiation and Radiant Heat.**—The passage of heat from a heated body is called *radiation*, and heat on its passage is *radiant heat.*

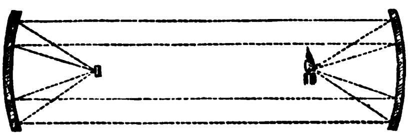


FIG. 239.—REFLECTION OF HEAT.

386. **Reflection of Heat.**—To prove that dark heat undergoes reflection, we can place a vessel of boiling water at the principal focus (see Par. 270) of a con-

cave mirror, when the heat-rays will be reflected; and if collected by another concave mirror, a thermometer placed at *its* principal focus will show a decided increase of temperature.

If a piece of ice is used instead of the vessel of hot water, the mercury falls. This would seem to indicate that *cold* is also reflected. Such is not the case. The cause of the fall is that the thermometer parts with its heat faster than the ice does, and it goes to the ice to raise its temperature, or to melt it.

To prove the refraction of heat we have the ordinary "burning-glass."

387. **Heat Reflected, Diffused, Absorbed, and Transmitted.**—Like light, all the heat which falls on a body is not reflected. Some of it is diffused (scattered in all directions), some of it goes into the body, and is either used up in doing work among the molecules or is transmitted.

388. **Different Bodies have Different Effects.**—Different bodies differ greatly in their power of radiating, of transmitting, of reflecting, and of absorbing heat.

389. **Difference in Radiation.**—If there be three vessels of equal size filled with hot water, one made of polished tin, one coated with isinglass and one with lamp-black, then in the same time there will be eight times as much heat *radiated* by the lamp-black as by the tin, and seven times as much from the isinglass as from the tin. As a general rule, metallic bodies are poor radiators, and the brighter and smoother the surface the poorer radiators they become. Good reflectors are commonly poor radiators, and the reverse. A body that radiates well will absorb well and reflect badly.

390. **Difference in Transmission.**—As regards *transmission* of heat, certain substances which are opaque to light allow heat to pass freely, and some transparent to light entirely cut off the heat. In the chapter on light we learned that blue glass allowed blue rays to pass through

and cut off the red: in the same way thin metallic foil will allow luminous rays to pass and cut off almost all the dark heat. Bad radiators are bad transmitters, for the bad radiators, like polished tin, *reflect* much of the heat that falls on them, and so transmit but little.

391. **Special Substances.**—Lamp-black (the soot from lamps) is an excellent absorber; it transmits no heat and reflects but little. Polished silver is a good reflector; it transmits nothing and absorbs very little. Rock-salt in transparent crystals transmits nearly everything; it absorbs none and reflects but little. Crystals of alum, equally transparent, will absorb nearly all the heat and transmit almost none. Ice is also a very poor transmitter.

392. **Dr. Franklin's Experiment.**—Dr. Franklin made the experiment of putting pieces of cloth of different colors on snow when the sun was shining. He found that the dark colors melted themselves into the snow farther than the light, from which he inferred that they were in general better absorbers. This is true in so far as it relates to luminous heat, but in the case of dark heat, such as we get from a stove, color does not seem to make any difference.

393. **Effect of Screens.**—A screen placed in front of a fire protects from heat. But, as it receives heat itself, it becomes in time a source of radiation. We do not feel the radiation so strongly, because the heat which it intercepts it sends out in all directions, and hence not so strongly in any one.

Exercises.—1. Should stoves be kept bright if we desire to have the most heat from them? Should teapots be of polished metal? cylinders of steam-engines?

2. Which is cooler in the direct rays of the sun, light clothing or dark? in a house by a hot stove?

3. If we had a convex lens of alum and one of rock-salt exposed to the sun, in the focus of which would be the higher temperature?

4. How much is the heat diminished by moving twice as far from its source?

5. The dark heat-rays are found near the red end of the spectrum: which have the more rapid vibration, the dark or the luminous waves?

6. Is a glass screen as effective in front of an open fire as in front of a stove?

CONDUCTION OF HEAT.

394. **Conduction of Heat.**—When heat travels along by communicating motion from one particle of a body to another, the movement is called *conduction of heat.* Radiation is movement through ether, and radiant heat has the same velocity as light. Conduction is a comparatively slow process.

Experiment 140.—Heat one end of an iron rod to which nails are stuck by little pieces of wax. The nails will drop off one by one as sufficient heat reaches them to melt the wax.

FIG. 240.—CONDUCTION OF HEAT.

395. **Different Conducting Power.**—Different bodies differ in their power to conduct heat.

Experiment 141.—Hold an iron rod in the fire till it begins to feel hot. Hold a glass rod the same time, no perceptible increase of heat is felt.

Experiment 142.—Coat bars of various substances with wax, and place them all with one end in hot water. Notice how far on each the wax melts.

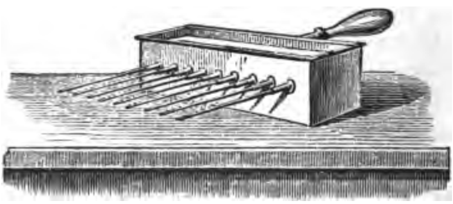


FIG. 241.—DIFFERENT CONDUCTING POWER.

396. **Conducting Power of Metals.**—The following table gives the relative conducting power of certain metals:

Silver	100	Iron	12
Copper	74	Lead	9
Gold	53	Bismuth	2
Tin	15		

397. Conducting Power of Liquids and Gases.—Liquids and gases are poor conductors of heat.

Experiment 143.—Pack snow in a test-tube, and apply heat near the top. The water may be made to boil at the top while the snow is still unmelted at the bottom.

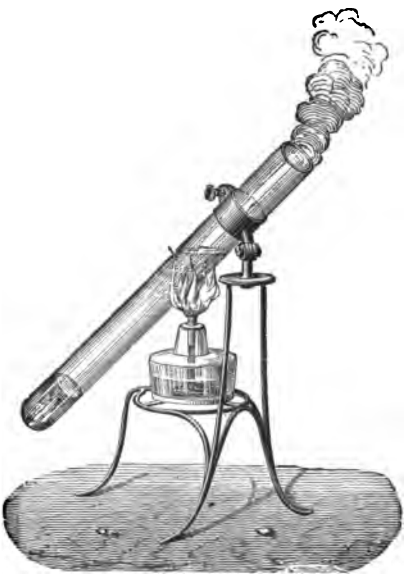


FIG. 242.—POOR CONDUCTING POWER OF WATER.

398. **Conducting Power of Air.**—Dry air is a poor conductor of dark heat, a better one of luminous heat, but moist air is a worse conductor of both dark and luminous heat. The sun's heat comes to us through the air and heats up the earth. This then radiates dark heat, part of which is retained by the moist air surrounding it.

On high mountains the sun's luminous heat penetrates the rare air without warming it, and heats the mountain-tops. But the radiated heat from them is not retained, but quickly passes off, leaving the air cold. A cloud or fog over the mountain would change all this.

The glass of a hot-house produces the same effect as the moisture of the atmosphere.

An open fire gives out luminous heat, which penetrates the air of a room readily and warms up the surfaces of solid bodies. The heat from a stove or a furnace, on the

contrary, is more retained in the air. In the one case we keep warm by direct radiation, in the other by living in a warm atmosphere.

Clothing is especially useful in retaining a layer of warm air next the body. This by its poor conducting power prevents the passage of heat outward.

399. **Sensation of Heat.**—Our *sensation* of heat depends largely on the conducting power of the substance with which we are in contact. A carpet and an oil-cloth lying side by side may actually contain the same amount of heat. But if we touch both at the same time, the best conductor, the oil-cloth, conducts away from us the most heat, and so seems colder. It would produce the same effect in a thermometer, carrying away heat from the mercury.

Exercises.—1. Why is a glass tumbler more readily cracked by hot water than a vessel of better conducting power?

2. Why are the handles of teapots often made of glass or porcelain?

3. Why is woollen clothing warmer than cotton?

4. Why can a man plunge his hand into molten iron without being burned?

5. A brass cylinder covered with thin paper may be held in a flame for some time without having the paper scorched; not so when the cylinder is made of wood: why is this difference?

6. Why do hollow walls and double windows keep a house warm?

7. Would a hot-house be effective if heated by a stove from above instead of by the sun?

8. Why does the coming of clouds frequently make it warmer?

9. Are our sensations safe judges of temperature? Having had one hand in ice and the other in hot water, what will be the effect if we plunge both into tepid water?

CONVECTION OF HEAT.

400. **Convection of Heat.**—When a liquid or a gas is heated from below, the warm particles rise and are replaced by colder heavier ones. This makes constant circulation, which carries the heat about. This method of conveying heat by actual transmission of the particles of water is called *convection of heat.*

This can be well observed in the boiling of water, as seen in Experiment 136.

The diffusion of heat by currents is shown on a large scale in the Gulf Stream. This great body of warm water, which is a result of the heating of the earth at the equator, conveys this heat to the coasts of England and Norway.

THE STEAM-ENGINE.

401. **History of the Steam-Engine.**—About the year 1700 a machine to pump water out of mines by the aid of steam was invented and used in England, but about 1775 James Watt,[1] a Scotch mathematical instrument-maker, invented, and soon after brought almost to its present perfection, the stationary engine. The first locomotive-engine was built and run in 1804 or 1805 in England. But it was not until 1829 that the first really efficient locomotive was built by George Stephenson,[1] an Englishman.

402. **The Stationary Engine.**—Fig. 243 shows the essential features of the stationary engine. M is the boiler, where the steam is generated. At first we will suppose the valve *b* to be shut and *a* to be open. The steam will pass from the boiler through *a* and drive the piston, *p*, to the bottom of the cylinder. *a* is now closed and *b* and *d* are opened. While the steam is now passing through *b* to the under side of the piston and pushing it up, that steam which was above the piston is rushing through *d* down to the condenser, I, where it is condensed by the cold water there, leaving a vacuum above the piston, so that there is no obstacle to its ascent. When it reaches the top of the cylinder again, *b* and *d* are closed and *a* and *c* opened, and so on constantly. The figure shows how the up-and-down motion of the piston turns the fly-wheel, R, and thence by a belt or otherwise the machinery is set in motion.

[1] Watt and Stephenson were two of the greatest benefactors to mankind that ever lived. Samuel Smiles has written lives of both these men that would be exceedingly interesting and valuable to every one who studies this book.

403. **The High-Pressure Engine.**—The condenser adds much machinery to the engine, and requires a constant supply of cold water. Many engines, therefore, have no condenser; *d* and *c* open directly into the air. The air condenses the steam and itself fills up the vacuum, so that the piston in returning has to drive the air out of the cylinder ahead of it. *With* a condenser the piston is driven back through a vacuum, so that there is no resistance; *without* it the piston must be driven against the pressure of the atmosphere, nearly 15 pounds per square inch.

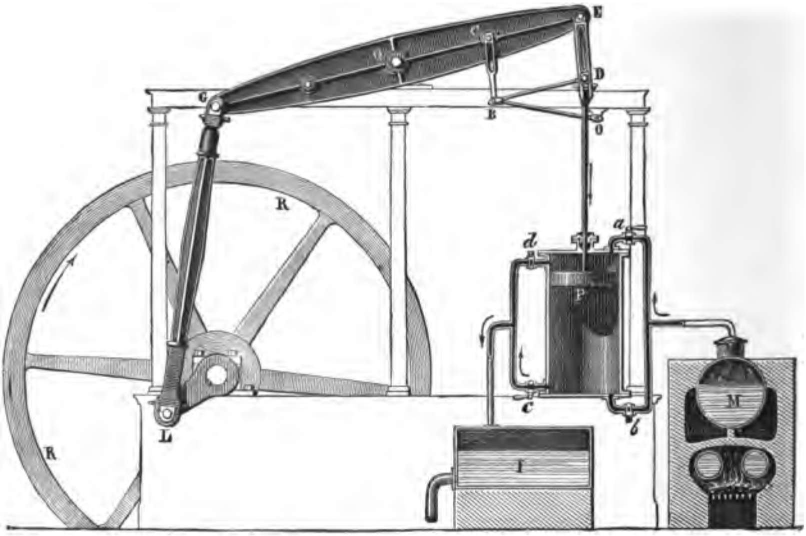


FIG. 243.—STATIONARY ENGINE (LOW-PRESSURE).

When there is no condenser, the pressure of the steam must be about 15 pounds per square inch greater or higher to do the same work: hence an engine without a condenser is called a *high-pressure engine*, while one having a condenser is called a *low-pressure engine*. Almost all small stationary engines are high-pressure. This is especially true of portable engines, such as steam fire-engines, engines for work-

ing thrashing-machines, portable saw-mills, and the like. A high-pressure engine of course takes more fuel to do the same work. In a high-pressure engine the steam escapes from the cylinder in puffs, and this puffing is characteristic of this kind of engine.

404. **How the Valves are worked.**—In Fig. 243, for the sake of simplicity, it is supposed that the four valves are worked by hand. Fig. 244 shows how one valve does the work of all four. In the right-hand figure the valve is raised, which allows the steam coming in by the pipe on the left to flow into the lower part of the cylinder, while the peculiarly-shaped valve, called a D-valve, connects the pipe from the other end of the cylinder with the opening *o*, which leads into the condenser. When the piston reaches the upper end of the cylinder, an arm, worked by the engine itself, pushes the D-valve down, as seen on the left, and the upper part of the cylinder is connected with the boiler, while the lower part is connected with the condenser.

405. **Three Important Attachments to the Engine.**—An opening is made in the top of the boiler, which is closed by a close-

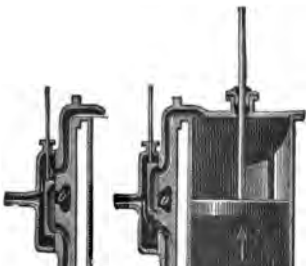


FIG. 244.—D-VALVE AND CYLINDER.

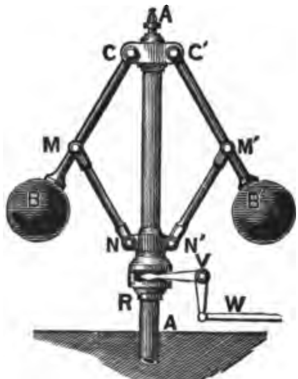


FIG. 245.—THE GOVERNOR.

fitting plug of iron. This plug is held down by a lever-arm, at the end of which is a certain weight. When the pressure of the steam

becomes so great that there is danger of its bursting the boiler, it lifts this plug and escapes. This is called the *safety-valve.* A gauge is usually attached to boilers, which shows how great the pressure upon each square inch is at any time.

Fig. 245 shows a very ingenious invention of Watt's, which automatically controls or governs the speed of the engine; hence it is called the *governor.* This is so attached to the engine that it revolves. If the engine runs too fast, the governor will revolve faster, and the two large balls will be thrown outward by centrifugal force. This raises R, which works a valve and shuts off a part of the supply of steam from the cylinder. If the engine runs too slow, there is less centrifugal force, and the balls fall, which lets more steam into the cylinder.

The large wheel seen in Fig. 243 is the *fly-wheel.* It is a heavy iron wheel, and, besides running the belt which drives the machinery, it is of great use in equalizing the motions of the engine and in storing up power so as to overcome by its inertia sudden resistances to the machinery.

406. **The Locomotive.**—Fig. 246 is a section of a locomotive, showing its essential parts. In order to reach the smoke-stack the heated air and flames of the fire must pass through metal tubes. These tubes run directly through the boiler, and are very numerous, thus giving a very large heating surface. They are surrounded by the water in the boiler, and without these tubes it would be impossible to make steam fast enough to drive the locomotive at high speed. The cylinder is seen in front, and right above it is the D-valve, worked by the small rod which may be seen connecting it with the other machinery. The locomotive has no condenser, and is therefore a high-pressure engine. The steam escapes from the cylinder through the D-valve into the blast-pipe *v*, and thence up the smoke-stack. This greatly increases the draught of the fire, and causes the puffs of sound that we hear, and the puffs of smoke that we see. Increasing the draught by letting the waste steam escape through the chimney, like the tubes in the boiler, was a very important invention, as it keeps up a hotter fire and thus generates steam faster.

Every one who uses this book is strongly urged to examine thoroughly engines of both sorts. Engineers will generally be willing to explain all their details.

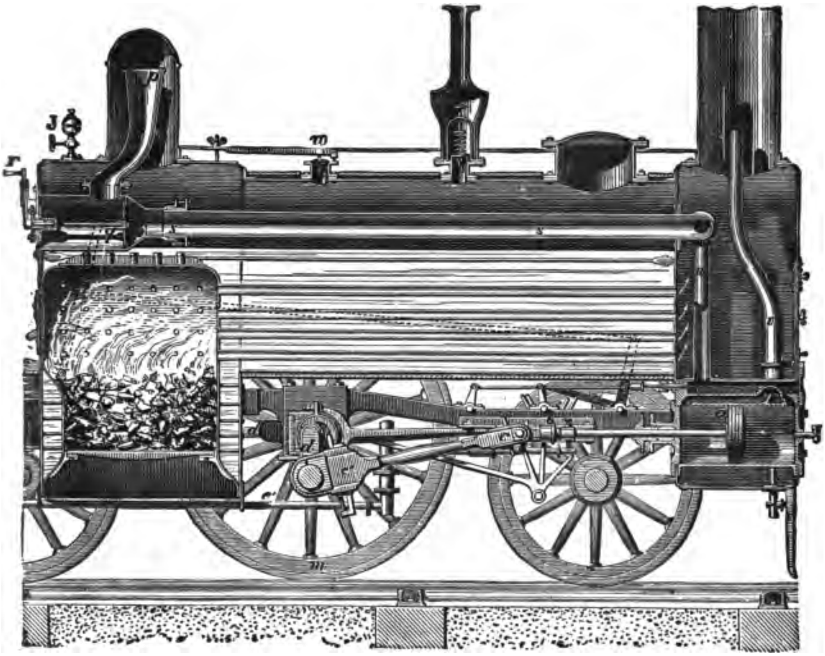


FIG. 246.—THE LOCOMOTIVE ENGINE (HIGH-PRESSURE).

407. How the Power of the Steam-Engine is estimated.—The power of an engine is usually estimated in *horse-power.* Watt estimated that a horse could raise 1000 tons one foot high in an hour.[1] An engine that can do that much work is a one horse-power engine; one that can lift 5000 tons one foot in an hour, or its equivalent, is a five horse-power engine. It is found that the steam produced from one cubic

[1] The raising of one ton 1000 feet in an hour, of half a ton 2000 feet in the same time, or any other equivalent, would be one horse-power.

foot of water will just about raise 1000 tons one foot per hour, so that an engine which can change five cubic feet of water into steam each hour is a five horse-power engine.

The student will not fail to notice that the steam-engine is a notable example of the conversion of energy. Heat is changed to mechanical force by the agency of steam and the machinery of the engine. Neither the steam nor the engine *produces* the power, and in the most efficient engine they really waste a great deal of it. But they are the best means yet found of converting the molecular motion or force of the heat into mechanical motion. Nor will it be forgotten that the power to produce heat is in the coal, and was stored away by the sun's light and heat ages ago in the forests which produced our coal-beds. So it is really the sun's light and heat shed upon the earth many thousands of years ago that are drawing all our railway-trains, driving all our steamships, and moving all our steam machinery to-day.

General Exercises.—1. Find the degree in the Centigrade scale which corresponds to 118° F., and that which corresponds to 140° F.

2. Find the degree in Fahrenheit's scale which corresponds to 15° C., and that which corresponds to 35° C.

3. A piano which has been tuned in a drawing-room in a morning may produce discords in the evening, when the room is heated by the pressure of a large evening party: explain this.

4. A flask with a long neck contains alcohol, which fills the flask and rises to some height in the neck; the flask is placed in hot water, and the liquid at first *falls* in the neck as if it were contracting: explain this.

5. Show that 30 cubic inches of air would expand to about 41 in passing from 0° C. to 100° C.

6. A gas measures 98 cubic inches at 185° F.: find what it will measure at 10° C. under the same pressure. *Ans.* 77, about.

7. If 50 cubic inches of air at 5° C. *below* 0° C. are raised to 15° C. under the same pressure, find the volume. *Ans.* 53.8, about.

8. Air which is known to have a volume of 100 cubic inches at 0° C. is found to have expanded to 120 cubic inches without any change of pressure: determine the temperature. *Ans.* 54.6°.

9. Find what weight of ice at 0° C. will be melted if put in a pound of water at 50° C. *Ans.* 10 ounces.

10. A mixture is made of 3 pounds of water at 12° C. with 3 pounds of water at 16° C.: find the temperature of the mixture. *Ans.* 14°.

11. A mixture is made of 4 pounds of water at 7° C. with 6 pounds of water at 12° C.: find the temperature of the mixture. *Ans.* 10°.

12. Unglazed pottery is sometimes used to hold water and to keep it cool: explain this.

13. Carbonic acid may be reduced to the liquid form by strong pressure; when the pressure is removed, the liquid returns to the state of gas, but some of it becomes *solid* carbonic acid: explain this.

14. A pound of iron at 99° C. is immersed in a pound of water at 0° C.: find how many degrees the temperature of the water will be raised, taking the specific heat of iron at .1. *Ans.* 9.

15. The air on a high mountain may be intensely cold although the sun is shining and no clouds exist: explain this.

16. The bulb of a mercurial thermometer is exposed to heat: will any difference be produced in the rate of rising of the mercury if the bulb is covered with silver foil?

17. Suppose we are provided with bars of copper, silver, gold, and platinum: explain how we must proceed to determine the conductive power of these metals.

18. A piece of platinum may be held in the hand while one end is red-hot, but a piece of copper of the same length under such circumstances will speedily burn the fingers: explain this.

19. A kettle which has been in use for some time often becomes coated by a deposit on the inside, and then water takes a long time to boil in it: explain this.

20. A weight of a ton is lifted by a steam-engine to the height of 386 feet: find how many units of heat are required for this work. *Ans.* 1000.

21. A 68-pound cannon-ball strikes a target with a velocity of 1544 feet per second: supposing all the heat generated by the collision to be communicated to 68 pounds of water, how many degrees would the temperature of the water be raised? *Ans.* 2.

22. Show that to raise the temperature of a pound of iron from 0° C. to 100° C. an amount of heat is required which would lift about 3½ tons of iron a foot high.

CHAPTER VIII.

MAGNETISM.

408. **Magnets.**—A certain ore of iron,[1] frequently called loadstone, possesses the property of attracting metallic iron and steel quite strongly, and of attracting many other substances very slightly. A piece of iron, while near or in contact with a loadstone, possesses the same property, and a piece of steel placed in contact with the loadstone not only acquires this property, but retains it after having been withdrawn. The mountains surrounding the ancient city of Magnesia, in Asia Minor, were formerly famous for the production of loadstone, and from this city the name *magnet* has come to be applied to a piece of loadstone, or to any piece of iron or steel exhibiting the same power of attraction. When we have finished this chapter and the next, we shall have learned that there are many ways of imparting this interesting property to bars of iron and steel. At present we will consider magnetism, or this power of attraction, as a property communicated by the loadstone or "natural magnet." Good loadstones are small, inconvenient, and expensive, and bars of steel which have been stroked from end to end with the loadstone become magnets themselves, and are capable of transmitting the power to others. We shall, therefore, use steel magnets for our present experiments, and learn how to make them as we progress. A pair of such magnets, from three to six inches long, may be had

[1] An oxide of iron, usually of the composition Fe_3O_4. A large proportion of this ore of iron *does not* exhibit magnetic properties.

for a small sum, and will answer well for many of the following experiments.

409. **Poles of Magnets.**—Experiment 144.—Lay a magnet down on a bed of iron-filings, or in a box-lid containing a quantity of carpet-tacks or finishing-nails or "card-teeth." Be sure they are evenly distributed, so that all parts of the magnet may have equal access to them. Pick up the magnet, holding it horizontally by the middle. Notice that the small particles of iron are clustered at the *ends*, and that very few are to be found near the middle.

The attractive power of magnets resides at or very near the ends. These are termed the *poles* of the magnet. Every ordinary magnet has two poles.

410. **The Two Poles of a Magnet different in Kind.**—Experiment 145.—Touch two magnets together, end to end, and reverse one of them and then the other several times. Unless they are very different in size or strength, it will be found that in two positions they attract and adhere to *each other*, and in the remaining two positions they do not. Put temporary marks on the poles (if not already marked), so that they may be distinguished.

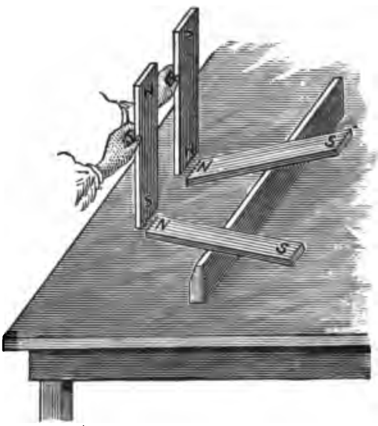


FIG. 247.—ACTION OF SIMILAR AND DISSIMILAR POLES.

Experiment 146.—Balance one of the magnets on the edge of a ruler. Bring each end of the other magnet from above quite near to each end of the balanced magnet. If the balancing is delicate enough, it will be found that the ends which in the previous experiment refused to attract each other, actually *repel* each other.

From these experiments it is evident that the two poles of a magnet, although capable of producing the same apparent effect in the iron-filings or tacks, are in some way different.

411. **Action of Similar and Dissimilar Poles.**—Experiment 147.—Hold two magnets of the same size and strength perpendicularly, one in each hand, and dip the lower end of each into a pile of

little nails, or something similar. Now bring the loaded magnets together, side by side. Reverse one of the magnets, and repeat the experiment. In one case the loads will remain adhering to the magnets after they are brought together, in the other case the loads will drop as soon as the magnets touch each other. Notice that the poles which are together when loads are *sustained* are those which were marked as *repelling* each other in Experiment 146, while those which are together when the loads are *dropped* are those which were marked as *attracting* each other.

It is evident that when the two poles unitedly sustain the double load, they must be *acting together*,—*i.e.*, they must be *similar*,—and that when the two poles which were strong separately refuse to hold any load unitedly, they must be acting *differently* or *oppositely*,—*i.e.*, they must be *dissimilar*. We are now ready to mark the poles of our magnets again, but not permanently yet. Put similar marks upon the poles that act together in sustaining the double load. From these experiments we derive the

Law of Action between Magnets:

Similar magnetic poles repel each other; dissimilar magnetic poles attract each other.

412. **Iron magnetized by Induction.**—Experiment 148.—With either pole of a magnet pick up a nail not too large to adhere firmly to the magnet and to stand out from it in any position. Touch the free end of this nail to another nail of the same size or smaller. It will be attracted. If the magnet is strong enough, the second nail will support (suspend) a third, this a fourth, and so on.

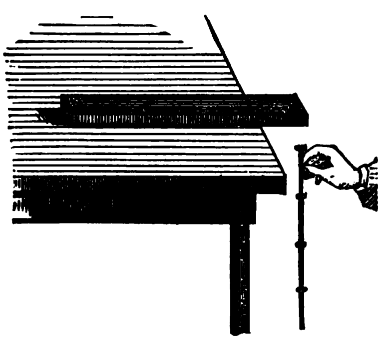


FIG. 248.—NAILS MAGNETIZED BY INDUCTION.

Experiment 149.—Touch the lower end of the chain of nails of the last experiment with that pole of the other magnet which is *dissimilar* to the pole from which the nails are hanging. It will adhere firmly. Form a chain again on a pole of one magnet, and approach its lower extremity with the *similar* pole of the other magnet. The nails will either be repelled or else they will let go their hold on one another and drop. If there are several nails in the chain they will probably all

drop, one by one, till the last one is reached, and it will be strongly repelled. Vary the experiment as follows: Rest the upper magnet on a table top, so that one pole will project beyond the edge of the table. Attach a chain of nails to this pole, and, when the magnet is nearly loaded, carefully pull the top nail downward a short distance from the magnet to which it adheres. If this is done carefully the nails will still adhere to one another, and exhibit the same properties of attraction and repulsion that they did while the upper nail was in contact with the magnet.

This experiment shows that there are two *dissimilar poles* in each nail while it is near to, or in contact with, the magnet; in fact, that each nail is then a *magnet* in itself. It is the steel magnet which, by its presence, *induces* the nails thus to act as magnets, and they are accordingly said to be magnetized by *induction*. Remember this word and the reason for its use, as it will be found frequently in this and the following chapter.

413. **Magnetization of Steel.**—Steel is magnetized by induction, as iron is, but it is very much slower in yielding to the magnet's influence. If one end of a needle be placed against a pole of a magnet it will exhibit very little attraction at its farther end. It requires repeated strokes across the end of a magnet fully to magnetize it, but when once magnetized, the steel, if good, retains its magnetism.

Experiment 150.—Lay an ordinary needle on one pole of a magnet, and, taking it by either end, draw it slowly across the magnet until it is torn loose from it. Lay it on the *other* pole of the magnet, take it by the *other* end, and draw it across as before. Repeat this a few times, being careful that the same end of the needle shall in each case *be pulled from the same end of the magnet.* The needle will be found to be permanently magnetic.

414. **Large Magnets.**—Large steel magnets may be made in a similar manner, except that the bar to be magnetized is generally laid on a flat table and one or two good magnets are drawn along it several times. The magnets which are thus used do not lose any of their own strength, though they impart the same amount to any number of bars. As a matter of fact, large steel magnets are generally made by contact with powerful electro-magnets. Further reference

to the subject must therefore be left till we reach electro-magnetism.

415. **Poles in the Particles of a Magnet.**—Experiment 151.—Magnetize two sewing-needles so that corresponding ends shall be similar poles, and test the strength of one with very small tacks. Cut it in half, and lay the pieces in a bed of the tacks. Each half will be a complete magnet with two poles. Compare the poles with the uncut needle. They will be found to correspond in *kind* with the poles to which they were nearest in the whole needle. Cut either half again and again, until the pieces are very small. In each case each piece will exhibit two poles, and *each pole will be found as strong as the original poles of the whole needle.*

We may make any number of short magnets by cutting up a longer one, the limit being reached only when the pieces become so small that we can no longer divide them with our cutting-tools. As we know the pieces of steel to be composed of infinitely smaller pieces than we can thus make, we may fairly conclude that *each particle* of a magnet possesses the poles and other essential properties of the whole magnet. This is also the case with the particles of a bar of iron which is rendered magnetic by the inductive influence of a magnet near it.

416. **Why a Bar is magnetized.**—We are now ready to state a little more clearly the theory of magnetism as exhibited in iron and steel bars. For the purpose of illustration, we will consider a bar to be a line of single particles placed end to end. When such a bar is brought sufficiently near the pole of a magnet, the particle nearest the magnet is *polarized* by induction; that is, it has two poles formed in it, one of which is attracted by the pole of the magnet, and the other repelled. The attracted pole is, of course, unlike the contiguous pole of the magnet, and the repelled pole is like it. This particle then acts by induction on the second particle, thus polarizing it; this acts on the third, the third on the fourth, and so on until all the particles are polarized, each one by the influence of the one next to it. When the particles are all thus polarized, each pole is engaged in attracting the pole next to it, *except those at the*

two extremities of the bar. These two, accordingly, are free to polarize and attract other pieces of iron, and they are therefore the poles of the magnet.

417. **Poles may be neutralized.**—If the two poles of a magnet be allowed to exert their attraction fully *on each other*, the magnet loses its power of attracting other bodies. This may be beautifully shown by the following:

Experiment 152.—Procure a piece of watch-spring about six inches long (your jeweller will willingly contribute it), and magnetize it by drawing it several times by alternate ends between the thumb and the respective poles of a magnet. Dip the poles of the magnet thus formed into small tacks. Carefully lift the load, and bring the poles together so as to make a circle of the spring. The load will drop, and any attempt to make it adhere to any part of the circle will be in vain if the spring has been evenly magnetized. In Experiment 147 the same effect was exhibited with the unlike poles of *two* magnets.

418. **The Attracted Body polarized.**—*Every particle of iron or steel attracted by a magnet is first polarized by the attracting magnet*, unless previously polarized by some other means. Fig. 249 suggests an experiment for verifying

FIG. 249.—MAGNETIC INDUCTION.

this law. The smaller piece is soft iron. ("Soft iron" is the technical name for good wrought iron, and is used in distinction from steel.) If the piece of soft iron in the above figure were of the same size in cross-section as the magnet, and the two were placed in contact, end to end, there would no longer be any poles at the *junction*, but there would be one at *each end* of the compound bar.

419. **Compound and Horseshoe Magnets.**—As the attracted piece of iron is polarized, it is evident that the magnet would attract each end equally if it could reach them both at once. To accomplish this end, magnets are frequently bent into the form of a capital U. Such magnets are called "horseshoe" magnets. The action of a horseshoe magnet on a piece of soft iron is indicated in Fig. 250. The soft iron is called the *keeper*. When so constructed as to move pieces of machinery, it is called an *armature*. To obtain the best results from a large magnet of any shape, it must be made by fastening several smaller bars together, parallel with one another. This makes a compound magnet. Fig. 250 is a *compound horseshoe* magnet.

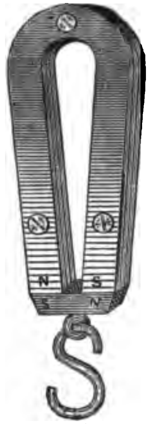


FIG. 250.—COMPOUND HORSESHOE MAGNET AND KEEPER.

420. **Lines of Force.**—Experiment 153.—Cut a groove in the face of a smooth board, so that a flat bar magnet may lie

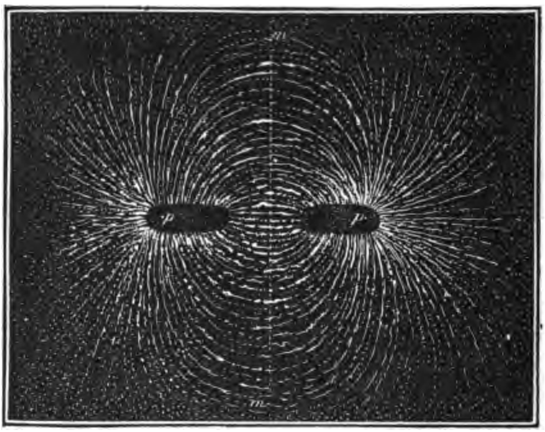


FIG. 251.—LINES OF MAGNETIC FORCE.

in it and have its upper side flush with the board. Place the magnet in the groove, cover it over with a smooth sheet of writing-paper, and

sift iron-filings [1] well over the paper. The position of the magnet is plainly indicated by the filings. Tap the board gently, and the filings will arrange themselves in a series of curves as shown in Fig. 251.

These curves are called the *lines of force* of the magnet. They show the direction which any other magnet, *placed in the plane of the paper*, and influenced by the covered magnet, tends to assume. The following beautiful experiment shows that these lines of force exist in all planes other than that which happens to be occupied by the paper.

Experiment 154.—Take an ordinary whalebone, or a similar piece of elastic wood, a few inches long, and string it as a bent bow, with a silk thread which has been unspun or combed out so that it will have no tendency of its own to twist. Tie a knot, or stick a piece of wax, in the middle of the string. Thrust a sharp needle, which has been magnetized, half-way through the knot or bunch of wax. Taking hold of the bow for a handle, approach a magnet with the needle. Whether the needle be held above, below, on either side, or in any oblique position with reference to the magnet, it will always assume a position corresponding to the direction of the lines of filings in the preceding experiment.

421. **Intensity of Magnetic Attraction.**—We notice in Experiment 153 that the filings near the pole are much more powerfully affected than those farther off. The needle of Experiment 154 was agitated most violently when near either pole of the magnet. When we approach the pole of a magnet with a piece of iron, we notice how the attraction seems to strengthen as the distance between them becomes less. With delicate appliances for measuring the pull or push exerted by magnets on other bodies, or on each other, we learn the

Law of Magnetic Attraction:

Magnetic attraction or repulsion varies inversely as the square of the distance through which it acts.

Notice that the laws of gravitation, sound, light, heat, etc., acting through different distances, are similar to this.

422. **Directive Tendency of the Magnet.**—**Experiment 155.**—Make a stirrup of paper, and hang it to a convenient support by a

[1] Iron-filings may be bought of a dealer in chemicals.

string that has no tendency to twist. Balance in the stirrup, one at a time, the two magnets which have been used in many of the previous experiments. After swinging backward and forward a few times, the magnets will each come to rest, pointing nearly *north and south*. It will be found that the ends of the two magnets which point in either of these directions are those which were marked as *similar* to each other after we had tried Experiment 147. We are now ready to mark the poles of our magnets permanently. Mark the pole which points northward "*N*," for north, or, rather, *north-pointing*, and mark the other end "*S*," for *south-pointing*.

All magnets tend to arrange themselves in nearly a north-and-south direction. This is because of magnetic property in the earth itself. Indeed, the whole earth may be considered as a vast magnet, having its magnetic poles near the geographical poles. How the magnetism of the earth is supposed to originate will be referred to in a subsequent chapter.

423. **The Magnetic Needle.**—A thin magnet, nicely balanced on a hard point, so that it may have great freedom of motion, is called a *magnetic needle*. Fig. 252 shows a common form.

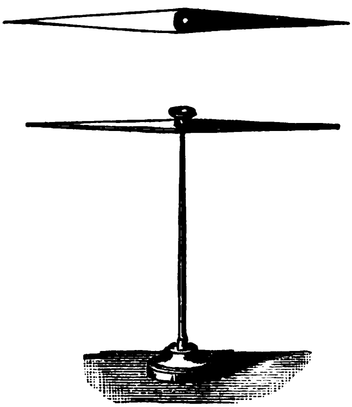


Fig. 252.—Magnetic Needle.

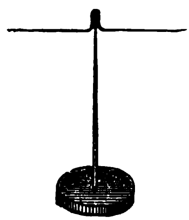


Fig. 253.—Home-Made Needle.

Experiment 156.—To make a *very good* magnetic needle, take a piece of watch-spring six or eight inches long. Straighten it between

the thumb and finger. Then, holding the middle of it in the flame of a lamp, bend it as nearly "double" as possible without breaking. Bend the ends back into a line with each other, as shown in Fig. 253. Magnetize each end separately. Wind a waxed thread around the short bend that is left, and balance on a needle held upright in a flat cork or a card. A little filing or grinding will be necessary to make it balance. With a point filed on the north-pointing pole the needle is finished.

424. **The Compass.**—A magnetic needle, when fixed in a frame which is graduated in degrees and properly equipped with sights and levels, forms the surveyor's compass. When the needle carries a circular card with the "points" (north, south, east, west, etc.) marked on it, the arrangement is the essential feature of the *mariner's* compass.

425. **Magnetic Declination.**—Although the compass was used a thousand years before the Christian era, it has long been known that in most places the direction of the needle is not a true north-and-south line. The deviation from the meridian is called the *declination of the compass.* Navigators must know the declination for a given place and allow for it. If the declination in a given place were *constant,* the allowance could easily be made, but it is subject to many variations, some extending over long periods, some over shorter periods, some regular and some irregular. As the greatest amounts of variation occur regularly and take place slowly, the compass is still a valuable aid to navigators and explorers. The declination at Philadelphia in 1883 is about 5° west. At London it is about 20° west.

426. **Magnetic Dip.**—If a steel bar be exactly balanced in its centre of gravity so that it may move about its support in any direction, and then magnetized, it will not remain level, but (in the Northern hemisphere) the north-pointing pole will incline downward, pointing towards a place considerably below the horizon. This is known as the *dip* of the needle, and a needle so balanced and magnetized is a *dipping needle.* The dip is greater the nearer we approach to the magnetic poles of the earth. In the Southern hemisphere the south-pointing pole dips down.

The dipping needle indicates the direction of the *earth's lines of magnetic force.* Therefore, if we know the position of the magnetic poles of the earth, latitude may be roughly determined by means of a dipping needle. Humboldt[1] relates that on one occasion he successfully directed his vessel into the port of Callao, on the west coast of South America, by determining his latitude in this way.

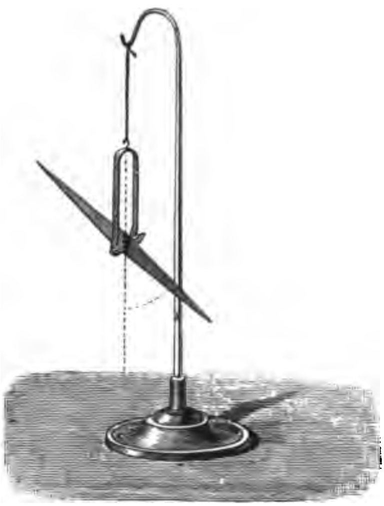


FIG. 254.—NEEDLE INDICATING BOTH DIRECTION AND DIP.

The dip of the needle at Philadelphia is about 75° with the horizon. The magnetic equator, or line of no dip, is somewhat irregular in shape, but crosses the equator in two points at an angle of about 12°, being that distance north of the equator in the Indian Ocean and the same distance south in Brazil. The north magnetic pole is about 10° north of the north shore of Hudson's Bay, and the south magnetic pole is in a corresponding position south of Australia.

427. **The nature** of the influence which magnets exert over bars of iron and steel to polarize their particles and make magnets of them, as explained in Art. 416, is little understood. We shall find in a succeeding chapter, however, that there is a close connection between magnetic phenomena and the existence of electric currents. A subject of much interest awaits us.

[1] Alexander von Humboldt, German, 1769–1859. An illustrious traveller, and an eminent scholar in many branches of learning. An *authority* on most scientific subjects.

CHAPTER IX.

ELECTRICITY.

I.—FRICTIONAL ELECTRICITY.

428. **Electrical Phenomena.**—It was known to the ancients that amber rubbed with some soft material possessed the power of attracting light bodies. It has since been discovered that many other substances exhibit the same property. The Greek name of amber is *elektron;* hence the name *electricity* came to be applied to the force thus developed, whether in amber or in any other substance. A gutta-percha comb, after being drawn through dry hair, in cool, dry weather, will pick up small tufts of cotton, pieces of paper, scraps of corn-stalk-pith, or any similar light substance. A sheet of thin paper rubbed with an eraser adheres tightly to the sheet under it, or to a wall. The force which holds these bodies together is electricity.

429. *Note.*—**Apparatus Needed.**—The following small articles will be needed frequently in trying electrical experiments, and should be kept on hand. Two *glass rods*, or heavy tubes, about 15 inches long, and at least ¾ of an inch in diameter; two smaller rods of *shellac* (sealing-wax or gutta-percha may be substituted for shellac); a silk pad, made by quilting together from three to six pieces of silk, about 8 inches square; a similar pad of flannel, or a cat's skin tanned with the fur on (a silk handkerchief and a flannel cloth will *do*); a lot of pith-balls from ¼ to ½ inch in diameter, made by cutting the dried pith of corn-stalks into shape with a sharp knife; a spool of sewing-silk; a spool of thread; a few bottles and other glass vessels; a supply of corks, pins, needles, wax.

In addition to these, a class should have a *proof-plane* and an *electroscope*. They are easily made. The proof-plane is a circular piece of tin about two inches in diameter, with a piece of glass tube or a gutta-percha pen-holder stuck to it with sealing-wax, for a handle. A very good electroscope may be made as follows (see Fig. 257). Procure a wide-mouthed jar of about a quart capacity; paste on the inside, on

opposite sides of the jar, two strips of tin-foil 3 inches long and 1 inch wide. These should extend upward from the bottom of the jar. Have a cork to fit the jar, and pass through it a stout wire. Make a stirrup on the lower end of the wire, say two inches from the cork. If convenient, solder to the upper end of the wire a circular tin plate of the same size as the proof-plane. Hang in the stirrup by the middle a piece of thin gold-leaf 4 or 5 inches long and ½ inch wide. It may be bought of a dealer in chemicals, or of a dentist, for a few cents, but, if it is not at hand, take silver-leaf, gilt paper, or very thin tin-foil instead. Be sure that the bottle is dry. Insert the cork, and run melted wax over it. The gold-leaves should open towards the strips of tin-foil.

In trying experiments in electricity all apparatus must be dry, and it should be warmed by the stove frequently while being used. Much of the glass of commerce contains metallic impurities, which render it unfit for electrical experiments. If failures occur, when everything seems right, try new glass. "Bohemian" glass has given the writer the most satisfaction.

Experiments in frictional electricity succeed best in *crisp winter weather*, when the atmosphere contains but little moisture. In summer weather it is sometimes difficult or impossible to produce electrical excitement.

430. **Electrical Attraction.**—Experiment 157.—Grasp a glass rod near one end and rub it briskly with the silk pad. A crackling noise and a sensation as of cobwebs on holding the rod near the face indicate that it is electrified. Hold it near a light rubber ball placed on a smooth table. The ball will be attracted, and will follow the rod around the table several times. A round collar-box or a hoop of any light material will answer equally well. Rub a rod of shellac with the flannel and present it to the ball or the hoop. The same result will follow.

431. **Attraction and Repulsion.**—Experiment 158.—Make a "wire loop" (such as is shown in Fig. 255) of sufficient size to hold the glass and shellac rods. Suspend it by a silk thread or narrow ribbon to a convenient support. Rest in it one of the glass rods. Rub the other rod with the silk, and bring it near the suspended rod. There will be an *attraction*. Repeat the experiment, but this time rub the first rod before placing it in the loop. On presenting the other glass rod, freshly rubbed, there will be a *repulsion*.

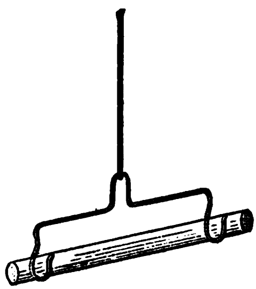


FIG. 255.—WIRE LOOP.

Follow the same course with the rods of shellac rubbed with flannel. They will act in the same way. Remove the electrical excitement from the surface of one of the shellac rods by drawing it through the hand. Place it in the loop and present a freshly-rubbed glass rod. There will be attraction. Rub the shellac rod and again present the rubbed glass. There will still be attraction.

432. **Two Kinds of Electricity.** — The last experiment shows that the two electrified bodies, though behaving similarly towards the unelectrified indicator, are different manifestations of the same force. It recalls the experiment which proved the difference between the two poles of a magnet. Here, however, both ends of the electrified body are similar. It is the *electric states of the two bodies,* the glass and the shellac, which are *dissimilar.* For distinction, the electric force developed on smooth glass by rubbing it with silk is called *positive electricity,* and that developed on shellac by rubbing it with flannel is called *negative electricity.* These are old names, and the theory which gave rise to them has been abandoned, but, as they have very distinct applications and are frequently used, they must be remembered and distinguished. The friction of many other substances produces electricity, but it all proves itself to belong to one or the other of the above classes.

The sign + is used in many of the figures which occur in this chapter to denote *positive* electricity, and the sign — to denote *negative* electricity. These are not to be read plus and minus, but positive and negative.

433. **Law of Attraction and Repulsion.**—Experiment 158 will have suggested the following law: *The two kinds of electricity attract each other, but each is self-repellent.*

434. No reason has been discovered why one body should exhibit positive electricity and another negative. When a substance whose nature is unknown is electrified, it must be tested by one whose electricity is known. To test a body, ascertain whether excited glass or excited shellac *repels* it.

435. **What is Electricity?**—We might further say that no reason has been discovered why a body should be electrified at all. Electricity is a state of strain which a body exhibits as an equivalent of the energy applied to produce it. It is a complete example of the conservation of energy. In the experiments which we have thus far tried, the energy applied in the rubbing of the rod appears as a force in the rubbed rod capable of moving light bodies. We shall see,

as we proceed, that it is capable of reappearing as energy of other kinds.

436. **To charge a Body.**—Experiment 159.—To each end of a silk thread two feet long attach a pith ball, and suspend the silk by the middle. Rub a glass rod with silk and touch it to the balls as they hang together. They will now repel each other and stand apart for a considerable time.

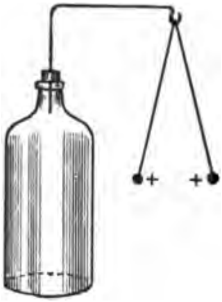


FIG. 256.—ELECTRICAL REPULSION.

This experiment shows that electricity passes from one body to another. Each ball has taken some of the positive electricity from the glass, and the two, being similarly electrified, repel each other. A body which has taken some electrical force from another is said to be *charged;* a body which has been electrified by friction is said to be *excited.*

437. **Neutral and Excited Bodies.**—If the excited glass and the excited shellac be rubbed or rolled thoroughly over each other, each will lose the principal part of its charge. This leads us to conclude that each is capable of undoing or neutralizing the electric state of the other. This is expressed by saying that the two electricities will *unite* with each other. If the positive charge of one body and a *correspondingly heavy* negative charge of another body unite, neither body manifests electrical excitement after the union. The bodies may then be said to be *neutral.* Nearly all bodies capable of electrical excitement are usually in a non-excited state. We may express this by saying that the two electricities neutralize each other in such bodies. When they are excited by rubbing, the *rubbed body* exhibits *one* kind of electricity and the *rubber* the *other* kind. Try the following:

Experiment 160.—Rub a glass rod with the silk pad (holding the pad in a piece of sheet-rubber, *e.g.*, the top of an old overshoe), and present the pad to some light pieces of feather or something of the

kind. There will be an attraction, showing that the pad is electrified. Rub the rod again, and suspend it as in Experiment 158. The pad and the rod will attract each other, showing that they are differently electrified. The neutral, inactive electricities of the two bodies were *roused up* in some manner by the rubbing, and arrayed themselves against each other, part of the negative of the glass going to the pad, and part of the positive of the pad going to the glass.

Experiment 161.—To show that the two electricities do exist in the glass before excitement, rub a glass rod with *flannel*, or, better, on a cat's skin. *It will repel excited shellac*, indicating that it is *negatively* electrified. To procure positive electricity on glass, be sure to rub it with silk.[1]

438. **Conductors and Insulators.**—If an excited rod be touched to one end of a metal bar, an indicator at the other end shows that the electric force is immediately felt there. If the same experiment be tried with a glass bar, the electricity does not manifest itself to any appreciable extent at the farther end. Substances which readily transmit electricity are called *conductors*. The metals, charcoal, wood, water, hemp, and animal bodies are conductors. Two or more bodies connected by conductors are said to be in *electrical connection.*

Substances which transmit electricity feebly, or not at all, are called *insulators*, and a body *in contact with nothing but insulators* is said to be *insulated.* Dry air, shellac, rosin, beeswax, glass, india-rubber, and silk are among the most common insulators. As the human body is a conductor, it is evident that we should handle all electrified bodies by means of insulating handles if we would have them retain their electrical condition. Particles of dust and moisture which may collect on insulators have some power of con-

[1] When we speak of "two electricities existing in" a body, we are using language rather loosely, as electricity is not a *substance*, but a *force*. It would be more accurate to say that a body is capable of exhibiting either phase of the electric force; but we could not describe the experiments in the more strict language without making very tiresome sentences, so philosophers agree to use the simpler expressions for convenience, and ask their students not to picture to themselves electricity as a *material.*

duction: hence the caution to keep all electrical apparatus while in use *clean* and *warm*.

439. **Electrical Induction.**—As a magnet may communicate its power of attraction to a piece of iron at a short distance from it, so an electrified body may induce electrical excitement in another body without touching it.

Experiment 162.—Bring the excited glass or shellac rod near the knob or plate of the gold-leaf electroscope (Art. 429). As it approaches the leaves will diverge, and as it recedes the leaves will come together. Repeat several times in succession.

FIG. 257.—GOLD-LEAF ELECTROSCOPE.

The gold-leaves in this experiment were similarly electrified by induction, hence they repelled each other. For a full understanding of many of the phenomena which we are about to study, it is necessary for us to bear constantly in mind that *any excited body tends to excite by induction insulated bodies near it.* It is also essential that we should be able to tell, in any case, what *kind* of electricity one body induces in another, or in different parts of it.

Experiment 163.—Touch the proof-plane (Art. 429) to an excited glass rod, and then to the top of the gold-leaf electroscope. The leaves become charged, and remain diverging after the proof-plane is withdrawn. Carry a second charge from the glass to the gold-leaves. They diverge more widely. While they are still divergent, carry to them with the proof-plane a charge from excited shellac. The negative electricity neutralizes some or all of the positive in the leaves, and they fall towards each other.

440. **To Test the Kind of Electricity.**—This experiment indicates how we are to test the kind of electricity on any excited surface. Diverge the gold-leaves with a known kind. While they are still divergent, the contact of a body *similarly* electrified produces *more* divergence, and the contact of a body *oppositely* electrified produces *less* divergence.

441. Body electrified by Induction.—Experiment 164.—Procure or make a cylinder whose length is about four times its diameter. Eight and two inches are very convenient dimensions for these experiments, though very much smaller will do, and very much larger are better when we have much electricity. The ends must be convex, as shown in Fig. 258. The outside of the cylinder, ends and all, must be of some conducting material. Turned wood covered with tin-foil answers admirably. A hollow tin can with round ends would be good. An egg, an apple, a croquet-ball, would do. This is an *induction cylinder*. Support it on glass or wax, or hang it by silk. Hold an excited rod near one end. *While it is held there*, touch first one end and then the other of the induction cylinder with the proof-plane, and test each with the gold-leaves. The end next to the excited rod will be found in the electrical state *opposite* to that of the rod, and the farther end will be found *similar* to the rod. Try the middle of the cylinder. It will be found neutral.

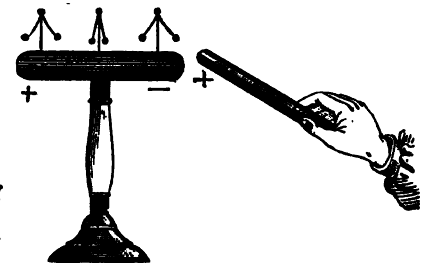


FIG. 258.—INDUCTION CYLINDER.

442. Cause of Attraction by an Electrified Body.—All bodies electrified by induction show the above result. The electrifying body attracts the opposite and repels the similar electricity, in accordance with Art. 433. This brings us to an important principle of electrical attraction,—viz., *a body attracted by an electrified surface is first electrified by induction, and the apparent attraction of the bodies is really the attraction of the opposite kinds of electricity.*

443. Why a Body is charged.—The body which electrifies another by induction does not thereby lose any of its charge; but if a body which is electrified be brought into *contact* with one which is not, the electrified body *does* lose some of its electricity. Suppose the first body to be positively electrified. Part of the positive electricity combines with the negative which has accumulated on the nearest part of the other body. The farther extremity of the second body remains positively electrified by repul-

sion. When the electrifying body is withdrawn, this positive electricity disposes itself symmetrically over the surface of the body, and the body is *charged.*

444. **Insulators easily charged.**—It will have been noticed by the pupil, before reaching this point, that the substances upon which we develop electricity are insulators. This is largely because glass, shellac, etc., are easily excited, but partly because the very fact of their being insulators enables them to *retain* the charge which is developed on their surface. When any point of a charged *conductor* is placed in electrical connection with another conductor of very large size (the earth, for example), the whole charge passes off, and the body is said to be discharged. In order to discharge a charged *insulator*, all parts of its surface must be placed in electrical connection with a large conductor.

445. **Action of Points.**—Before going into the study of electrical machines it will be necessary to observe and remember the effect of *pointed conductors* on a charge of electricity.

Experiment 165.—Touch an insulated cylinder (see Fig. 258) with an electrified body. While the balls are divergent, point a needle or an open penknife towards it. The balls will fall together, and remain so after the point is withdrawn.

446. **The Earth is the Great Reservoir** of electricity, both positive and negative. A person standing on an ordinary floor is in electrical connection with the earth. An electrified body tends to draw towards it the opposite electricity of any object sufficiently near. (Art. 441.) When the surfaces are curved, as in the induction-cylinder, the electricity, though attracted by the inducing body, is kept back by the insulating air, a large surface of which is opposed to the electricity, and thus prevents its passage. When the surface at the place to which the electricity is drawn by induction is very small, as the needle-point, the air can oppose but little resisting surface, and the electricity flies across the insulating space to the inducing

body. If the point be attached to an insulated conductor, instead of being held in the hand of a person standing on the floor, the conductor will be found charged with one kind of electricity by the escape of the opposite kind from the point.

447. **The Electric Spark.**—When a charge of electricity is *sufficiently intense*, it will pass through an insulator from one conductor to another though the surfaces be round and smooth. Such a charge, in passing through the insulating medium (mostly air), produces the *electric spark.*

448. **Electrical Machines.**—We have now learned all the principles involved in the construction of electrical machines, and, as many experiments succeed best when an electrical machine is used, we shall describe a few common forms.

449. **The Plate Electrical Machine.**—The circular glass plate G (Fig. 259) is clamped to the axle and turned by the handle. The

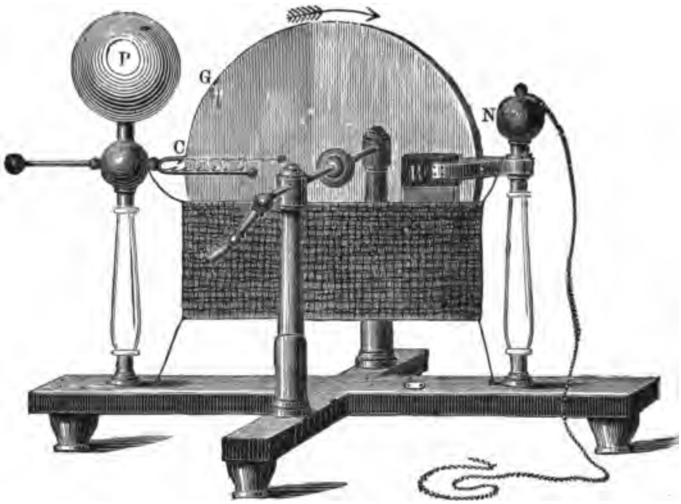


Fig. 259.—Plate Electrical Machine.

arrow shows the direction of rotation. Two rubbers at R are pressed by springs against opposite sides of the plate. These springs are connected with the ball N, which is insulated on glass and forms the

negative conductor. On the opposite side of the plate is the positive or *prime* conductor P, also on an insulating support. The *combs* C are the points over which the negative electricity is to flow to the glass plate. They are of brass. The rubbers may be chamois-skin coated with "electrical amalgam." (This is a compound similar to the coating on a looking-glass. The rubbers have tallow spread over the face, and the amalgam is spread evenly over this.)

When the handle is turned, the friction of the rubbers develops positive electricity on the surface of the glass and negative on the rubbers. The negative conductor thus becomes charged. As the rubbers are expected to take an unlimited quantity of negative electricity, it must be constantly carried away to the earth, or neutralized by positive from the earth, or from the prime conductor. As we generally wish to *use* the positive electricity, we connect the negative conductor with the ground by a chain dropped on the floor, or, better, attached to a stove-foot or a gas- or water-pipe.

When the plate with its positive electricity has turned half-way round, it acts by induction on the prime conductor, drawing the negative towards it and repelling the positive to the other extremity. At C the negative electricity finds the points of the "comb" and rapidly escapes to the glass, neutralizing the positive on its surface. The positive electricity on the prime conductor finds rounded surfaces, and remains till it becomes of considerable intensity. This action is continuous as long as the handle is turned. The lower half of the plate is always positively electrified. The upper half is neutral. Positive electricity may be drawn from any part of the prime conductor while the machine is worked, but it is more intense towards the outer end (the small ball in the machine here shown). The excellence of a machine, or of atmospheric conditions, is determined by the distance the charge will pass through the air, *as a spark*, from the end of the prime conductor to the knuckle of the operator or some other convex conductor. This distance is called the *length* of the electric spark.

If we wish to use the negative electricity from the machine, the ground-connection is made with the prime conductor. The negative spark is much shorter and less intense than the positive. Connection may be made between the two conductors. In this case the two kinds of electricity will neutralize each other, and the earth-supply will not be needed.

450. **The Cylinder Machine.**—Fig. 260 represents a cylinder machine, which is much less expensive than a plate machine. Any school-boy may make one. A large bottle (one that would hold from

one to four quarts) will answer for the cylinder. A glass rod, G, supports the prime conductor, C. This may be of wood, covered with tin-foil. Let the tin-foil extend so far as to the pin-points, P.

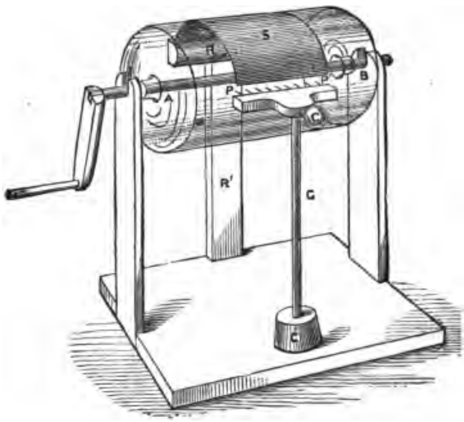


FIG. 260.—CYLINDER ELECTRICAL MACHINE.

R is the rubber, made of leather, or chamois, or silk, stuffed with wool. A silk apron, S, attached to the rubber and extending over the cylinder, adds to the certainty of its working. The rest of the machine is of dry wood.

451. Other Electrical Machines.—For explanations of many other interesting forms of electrical machines the reader is referred to more extended works on Natural Philosophy. The Holtz induction machine, and the Armstrong hydro-electric or steam electrical machine, are both capable of developing electricity in prodigious quantities.

Note.—With either of the devices explained above, most of the following experiments may be made to succeed in good weather. If the machine is home-made, be sure there are no sharp corners or loose edges of tin-foil where they would allow the charge to escape. Grind off edges of thick metal, and carefully press down with the finger-nail all edges of tin-foil. A coat of varnish helps insulators to keep dry.

452. Experiments in Attraction and Repulsion.—**Experiment 166.**—To the top of a stem of wood hinge a slender wooden toothpick, so that it will move in an arc of 90°. Stick the free end of the toothpick into a pith ball. A paper scale may be attached, as shown in Fig. 261. This is a *quadrant electrometer*. Stand it up in a gimlet-hoie carefully bored in the top of the prime conductor. It

indicates, by the rising of the pith ball, the presence of electricity in the conductor.

Experiment 167.—Hang from the end of the prime conductor a round metal plate by the centre. Hold under it a similar plate on which are placed a few paper or pith images. When the machine is operated, the images will dance vigorously between the plates. Vary this experiment by supporting the lower plate on glass. Explain both phenomena.

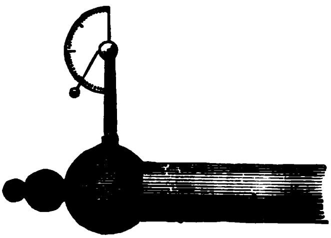


FIG. 261.—QUADRANT ELECTROMETER.

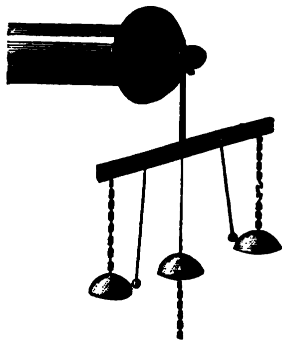


FIG. 262.—ELECTRICAL CHIME.

Experiment 168.—Suspend three bells, as shown in Fig. 262. Any bells will do. Suspend those at the end by conductors, and the middle one by silk. Suspend two little metal clappers by silk. Let a chain or wire drop from the middle bell to the floor. Operate the machine and hear the result.

Experiment 169.—Suspend a light figure of a boy in a silk swing a foot long. Arrange the swing so that the figure will hang midway between the prime conductor and a metal knob, or a knuckle held a few inches distant. Let the machine be turned. Devise a see-saw, a pump-handle, or a man sawing wood to be operated by electricity.

Experiment 170.—Grind to a point a stout wire six inches long. Bend the wire at right angles near the point. Insert the other end into the hole in the prime conductor. When the machine is worked, hold a lighted candle at the point of the wire. The flame is blown from the point. This is because the molecules of the air are successively charged by the electricity of the point, and are repelled from it.

Experiment 171.—Stick four or six of these sharpened and bent wires into a cork, so that they will all be in the same plane and balance horizontally. Insert a thimble or a lamp-extinguisher in the cork, and push the wires in against it. Balance on a straight sharp wire which stands in the hole in the prime conductor. The points and the molecules of air *repel each other*, causing the "flyer" to revolve (Fig. 263).

Experiment 172.—Cut a large number of very narrow strips of thin paper. Bind them together at one end by a wire, and hang on the prime conductor. Turn the machine.

Experiment 173.—Make a very small hole in the bottom of a tomato-can. Partly fill the can with water, and hang on the prime conductor by a wire. If the water drops slowly from the hole before the machine is operated, it will be forced out in a diverging spray on the turning of the handle.

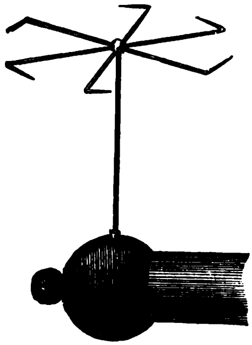


FIG. 263.—ELECTRICAL FLYER.

453. The Electrophorus, Fig. 264, is a very simple and at the same time a very instructive instrument sometimes used for the development of electricity. Any boy or girl may make one. The lower disk, or *plate*, is of resin, which has been melted and poured into a tin vessel a half-inch deep, and a foot, more or less, in diameter. A tinsmith will furnish both the vessel and the resin (rosin). The *lid* is of metal, or of wood covered with tin-foil. It must be rather smaller than the plate. The handle is of glass or sealing-wax.

Experiment 174.—Stroke the plate of the electrophorus with a cat's skin or a piece of flannel. It will be negatively electrified. Holding the lid by the insulating handle, place it flat on the plate. After a moment's contact, remove it, and test with the electroscope. It is not appreciably electrified. Place the lid on the plate again, and *touch it with the finger* before removing it by the insulating handle. After it is lifted from the plate, touch it with a knuckle of the other hand. A spark will pass, showing that it is charged. Charge the lid again, and try it with the proof-plane and electroscope. Its electricity is positive.

FIG. 264.—THE ELECTROPHORUS.

Be sure to understand the action of the electrophorus before going further. It opens the way for easily understanding the Leyden (lī'den) jar and other *condensers* of electricity. When the lid was placed on the excited plate by the insulating handle, the neutral condition of the lid

was undone by the inductive action of the plate. Its positive was drawn to the surface next to the plate, and its negative repelled to the upper surface. When the lid was lifted by the insulating handle without having been touched by the finger, the two kinds of electricity reunited and neutralized each other as soon as the lid was out of reach of the inductive influence of the plate. In the other case, when the lid was touched by the finger, the repelled negative electricity found a way to the earth and escaped. Then, when the lid was lifted by the handle, the positive, having no negative to unite with, diffused itself over the surface as a charge. The important principle which the electrophorus illustrates is that when a body is electrified by induction, the *attracted* electricity is *bound*, and the *repelled* electricity is *free*. To render this more apparent, touch the proof-plane to the lid as it lies on the plate, both before and after it has been touched by the finger. The electroscope detects negative electricity in the first case, and no charge in the second case.

In the electrophorus we are to consider a thin layer of air between the lid and the plate, except at the comparatively few points of contact. The resin being a non-conductor, the positive electricity of the lid cannot pass to the surface of the plate by way of these points, so it is simply held as near the plate as possible. The lid may be repeatedly charged from the plate after it has been *once* excited, which would be impossible if the lid, touched by the finger, came in contact with the whole plate. Although air is an insulator, a very thin layer of it offers but feeble resistance, so that no considerable charge can thus be obtained. A thin layer of *glass* offers much more resistance to the *passage* of electricity than the same amount of air does, but it does not interfere with *induction*. Two conductors separated by glass, may therefore be heavily charged with the two kinds of electricity, each holding the other bound, and neither showing its

presence when tested by a neutral body. Such an arrangement is called a *condenser*.

454. **The Leyden Jar.**—The most common form of condenser is the Leyden jar, so called because the discovery which led to its construction was made at Leyden about the middle of last century. As bought of an instrument-maker, it consists of a glass jar (see Fig. 265) with coatings of tin-foil inside and out, covering the bottom, and

FIG. 265.—DISCHARGING LEYDEN JAR.

the sides about two-thirds of the way to the top. A rod, piercing the cork, ends above in a ball or ring, and below in a chain or wire reaching to the bottom of the jar. To charge the jar, take it in one hand by the outside coating. Present the knob to the prime conductor. Sparks of positive electricity pass from the conductor to the ball, and so to the inside coating. Each spark of *positive* thus conveyed to the *inside surface* of the jar holds bound against the *outside surface* a corresponding amount of *negative*, and repels its own amount of positive through the arm and body of the operator. A large number of sparks may thus be passed into the jar, each one increasing the amount of positive on the inside and the amount of negative on the outside, till the tension approaches its limit, when

the sparks become noticeably less vigorous. The jar is now charged, and if a conductor is made to reach from any point of the outside coating to the knob, the two kinds of electricity unite with great energy. This is *discharging* the jar. An experimenter uses for this purpose a bent or jointed rod with an insulating handle. Fig. 265 shows an ordinary Leyden jar and a jointed discharger. A heavy bent wire, with rings formed on the ends, will do. The discharge in this way is instantaneous. If a body capable of taking a small charge of electricity is suspended by a silk thread between two conductors which are in electrical connection with the two coats of the jar, it will carry successive charges of positive to the outside coat, and of negative to the inside coat, until the two are neutralized in both. The little clapper shown in Fig. 266 will swing between the bells and keep up a chime for an hour, under favorable conditions.

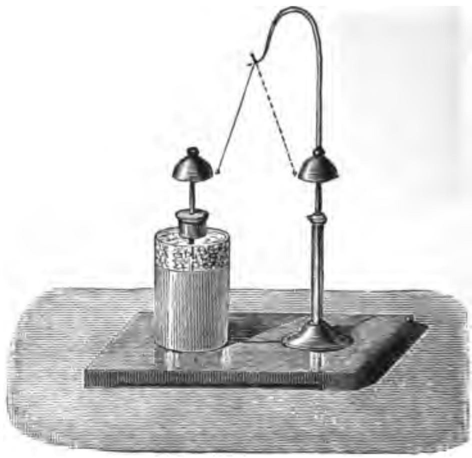


FIG. 266.—SLOW DISCHARGE.

455. **The Shock.**—When the discharge of a Leyden jar takes place through a conductor which is not very good, the human body, for instance, it produces a "shock" of more or less severity.

An accidental shock led to the invention of the Leyden jar. A pupil of an experimenter in Leyden was "storing" electricity in a bottle of water, by passing a rod into it from the prime conductor of a machine. The bottle was held in one hand, and after the machine

had been in operation a short time he attempted to remove the rod from the water with the other hand, when he was surprised and alarmed by receiving a shock. The news of this shock spread with great rapidity, and various modifications of the bottle of water were soon devised. The water served as the inside coat or conductor, and the hand of the operator as the outside coat. Let the pupil construct any or all of the following devices and take shocks from them.

456. Various Devices for giving Shocks.—Experiment 175.—Fill a small round bottle about two-thirds full of water. Put a piece of wire or a nail through a cork, and insert the cork in the bottle. The lower end of the wire must reach into the water, and the upper end must terminate in a ball or ring. Holding the jar in one hand, present the ball to a prime conductor, electrophorus, excited rod, or even a gutta-percha comb drawn through the hair. After the ball has taken several sparks, touch it with a knuckle of the free hand.

If it is at hand, paste tin-foil as a coating over the outside of the jar. A much larger condensing surface is thus obtained. Or, instead of the hand or tin-foil, set the jar in a vessel partly full of water, and dip a finger into the water while charging and discharging.

Experiment 176.—Paste a sheet of tin-foil on each side of a pane of glass. The foil should be smaller than the glass. Support the pane thus coated horizontally by one hand placed under the middle of it. Lay a coin on it. Bring the top coat, with the coin on it, near a prime conductor. After several sparks have passed, try to pick up the coin with one hand while the other is still in contact with the lower coat.

Experiment 177.—Let one pupil hold a pane of glass on the palm of one hand. Let a second pupil, who is standing on a stool with glass or rubber feet (see Exp. 180), rest his open hand flat on the glass, over the hand of the other, and bring a knuckle of the free hand near the prime conductor. After a few seconds, let them bring their free hands near together.

A class of inventive boys or girls will vary these experiments indefinitely. The shocks given by either of these devices, or by a regular Leyden jar, may be felt by several at once. To accomplish this, let all form a circle by clasping hands. When the circle is complete, break it in *one* place, and let the two persons thus separated touch, one the outside and the other the ball of the charged Leyden jar, or the corresponding parts of any other device.

A Leyden jar of a capacity of one quart will furnish a shock sufficiently severe for one person, though two or three times the amount of surface which it contains might be discharged through the human body without producing permanent injury. A large number of persons may take the discharge of a larger jar without injury.

457. The Discharge Instantaneous.—Experiment 178.—To prove that the discharge of the Leyden jar by a conducting rod (and

therefore presumably through the human system also) is instantaneous, set a wheel to rotating so rapidly that the spokes cannot be distinguished. Darken the room, and discharge a Leyden jar near the wheel. The separate spokes will not only be seen, but the wheel will appear to be stationary.

What is thus true of the spark of the Leyden jar is true of the electric spark under any circumstances. A rapidly-rotating carriage-wheel, or even a moving cannon-ball, illuminated at night by lightning, appears stationary.

458. **Heat and Light from Electricity.**—In previous chapters we have learned that resistance to motion causes the molecular vibrations which produce heat and light. The same effect is produced by resistance to the free passage of electricity. Passing over a good conductor, electricity produces no visible effects. The particles of bad conductors are so *shaken up* by their unsuccessful attempts to stop the flow of the electric charge through them that they frequently develop, first, heat, then light. The ordinary electric spark is caused by the heating of the molecules of air and "dust" in the path of the discharge. When the electric spark is produced in any other gas, the color of the spark is characteristic of that gas in a state of incandescence.

It is a well-known fact that barns and other buildings are burned by lightning. Lightning is ordinarily due to a discharge between two clouds differently electrified, but in cases in which objects on the earth are "struck" it is a discharge between a cloud and the earth. Should it strike a poor conductor of comparatively small size in its line of connection with the earth, it develops heat, sometimes enough to fire the object.

The following experiments exhibit the heating power of the electric spark on a smaller scale.

Experiment 179.—Present a very shallow metal cup containing a spoonful of ether or carbon bisulphide to the prime conductor of a machine. The spark will ignite the liquid.

Experiment 180.—Support a dry board about one by two feet on three or four stout tumblers, bottles, pieces of wax, or on feet shod

with india-rubber. This is an *insulating stool.* Stand on this stool, and take in one hand a chain or wire leading from the prime conductor. Take in the other a cold, dry icicle. Presented quickly to a vessel of carbon bisulphide, or to an ordinary gas-burner, the bisulphide or the gas may be ignited. This is pretty sure to succeed best if the gas-burner is used, and turned upside down, the icicle being presented from below (Fig. 267). Any water that may chance to form will then run back on the icicle instead of collecting on the end in a drop, which tends to dissipate the charge and prevent a spark.

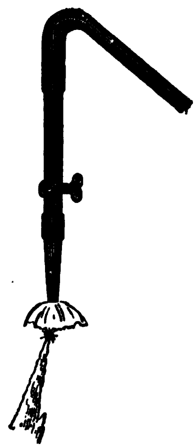


FIG. 267.—LIGHTING GAS WITH ELECTRIC SPARK.

Mixtures of oxygen and hydrogen, gunpowder, gun-cotton, and other explosives may be ignited by the electric spark. To fire gunpowder, the discharge must pass through a poor conductor, *e.g.*, a wet string, before reaching the metal ball suspended over the powder. Otherwise, by the suddenness of the discharge, the powder is blown away and not ignited.

459. **The Insulating Stool.**—The insulating stool affords a means of endless instruction and entertainment. A person standing on such a stool may be charged by connection with the prime conductor of a machine, or, standing near a conductor, he may be electrified by induction, or by presenting a knife-point or a row of pins to a prime conductor, or a revolving plate or cylinder, or excited rod, he may make a prime conductor of himself. In either case a few energetic schoolmates will think of a dozen expedients for testing his electric condition.

460. **Mechanical Effects of Electric Discharge.**—The electric shock is sufficient evidence that the passage of electricity through a poor conductor produces a shaking of the body, rather different from the molecular vibrations which produce heat. A loose block of wood is shaken by having a Leyden jar discharged through it. A piece of paper placed between the knob of a Leyden jar and the knob of the discharger is pierced by the discharge of the jar. A large jar, or several jars, will pierce thick cardboard, leather, and even glass.

461. **The Charge on the Surface.**—Delicate experiments have shown that the *charge of an electrified body lies wholly on the surface.* A hollow sphere of the thinnest metal will contain as heavy a charge as a solid ball of the same size, and so with a conductor of any external shape.

This may be experimentally proved by trying the inside and outside of a hollow charged conductor with the proof-plane and electroscope. Faraday[1] tried the experiment on a much larger scale. He built a box of wood twelve feet in each dimension, and covered it over with copper wires and tin-foil. This was connected with a powerful machine; and then (in his own words) "I went into the cube and lived in it, using lighted candles, electrometers, and all other tests of electrical states. I could not find the least influence upon them, or indication of anything particular given by them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every part of its outer surface."

So persistently does the charge keep to the outside that if a charged conductor be turned inside out any number of times without discharging it, the electricity shifts from one surface to the other, and is always found on that surface which for the time being is outside. Faraday devised for this experiment a linen bag, kept open by a ring at the mouth and turned either way by silk strings made fast to the bottom.

462. **Electrical Tension on Different Parts of a Surface.**—As has been intimated before, the amount of electricity on a given area of the surface of a charged conductor, or the electrical *tension*, varies unless the surface is a sphere. On a sphere the tension is equal at all points of the surface; on a cylinder with round ends it is greatest at the extremities; on an egg-shaped body it is greatest at the smaller end;

[1] Michael Faraday, English, 1791–1867,—one of the most noted philosophers of this century. His researches, abundant and striking in many branches of chemistry and physics, were especially so in electricity and magnetism. He was the discoverer of the present method of producing the current for electric lights, and of many other facts and methods of interest.

on a round disk it is greatest at the circumference; on a square disk it is greatest at the corners; and, in general, on symmetrical surfaces it is greatest at the parts farthest removed from the centre of gravity of the surface. Points or sharp edges connected with a surface, wherever situated, show the greatest tension, hence electricity escapes easily from them (Art. 446).

463. **Thunder-Storms.**—Every one now knows that lightning and thunder are due to electricity. The discovery was made by Dr. Franklin but little more than one hundred years ago. How the electricity is produced in the air we are not prepared to say with certainty, but the friction of masses of air over one another, and between the air and particles of moisture and snow, and the evaporation and condensation constantly going on, are capable of developing a large quantity of free electricity. But, however developed, the free electricity is there at all times, though we are sensible of its presence mainly at the time of thunder-showers. The phenomena attending these storms may be explained by the principles which we have just learned. When a large number of molecules of atmospheric moisture condense and coalesce to form a cloud, the body of the cloud becomes a conductor, and all the electricity which may previously have been in the space now occupied by the cloud comes to the surface and there acquires considerable tension. Different conditions give one cloud a charge of positive and another a charge of negative. It is plain that a discharge would take place between these clouds when they come sufficiently near to each other. Or a cloud heavily charged with either kind of electricity, on coming near a neutral cloud, would electrify it by induction, and a discharge might take place between the sides next to each other, which would be oppositely electrified (Art. 441). These are discharges between clouds. When a cloud heavily charged with electricity comes near the earth, it attracts the opposite kind of electricity by induc-

tion, and, as the earth has a large store to draw upon, or a large surface to distribute the repelled electricity over, the charge becomes very intense. In fact, we have a vast Leyden jar, the air acting as insulator. When the layer of air between the two becomes too thin to resist the tension of the opposing kinds of electricity, they combine, and we say the lightning came to the earth. High objects are most likely to be thus "struck," partly because the electric tension on such would be greatest, and partly because the insulating air between the two charges is thinnest over such places. The sudden motion of the air along the line of the lightning discharge, caused by its displacement, and also by its expansion and contraction on account of the intense heat, is the probable cause of *thunder*.

464. **Lightning-Rods.**—We are now ready to understand the effect of the *lightning-rod*. If the charge excited in the earth by the electrified cloud finds a pointed conductor extending towards the cloud, it tends to flow from the point to the cloud, and thus the electricity of the cloud becomes neutralized by the quiet discharge from the point, and the flash of lightning and the "striking" are avoided. The most efficient lightning-rods are those furnished with several points. Even then there should be several on a large building to render it comparatively safe against the intense charges which clouds sometimes carry.

Lightning-rods should be of ample size and good metal. Wrought-iron rods should be nearly an inch in diameter. Copper rods may be somewhat smaller. They should run several feet into the ground, and be connected with buried water-pipes (if they are large), or else they should terminate in several branches and be packed in coke, which is a good conductor.

465. **Electricity in Rarefied Air.**—Though the air in its ordinary state is a non-conductor of electricity, highly-rarefied air carries a charge with but little resistance. The aurora borealis, which is sometimes seen in our latitude, and more frequently in the far north, is probably due to

electric currents in the higher and rarer regions of the atmosphere.

A philosophical-instrument-maker will furnish an "aurora tube," with which a beautiful experiment may be performed. The tube has a pointed metal rod sealed into the upper end, and the lower end fits the air-pump. On exhausting the air and connecting the rod at the top with the prime conductor of a machine, the tube is filled with beautiful rosy streams of light, visible in a dark room. The electrified particles of air remaining in the tube, and which produce the light, are attracted like other electrified bodies, and the streams may be diverted towards the hand placed against the outside of the tube. In a succeeding section the subject of electric currents in rarefied gases will be more fully treated (Art. 514).

Exercises.—1. Two boys stand on different insulating stools, and one strokes the other a few times with a cat's skin: what will be the difference in their condition, and how may it be shown?

2. A girl on an insulating stool presents a row of pins to the prime conductor of an electrical machine in operation: what is her electrical condition?

3. If the induction-cylinder of Experiment 164 be touched to the prime conductor of a machine, what will be its condition after being removed?

4. Let the pupil draw a diagram representing three insulated conductors in a row, but not touching, that at one end connected by wire with the prime conductor and that at the other end with the negative conductor: indicate by the signs + and — the condition of each end of the middle cylinder.

5. If an excited rod be held over some very small pith balls lying on a table and then over some others lying on a pane of glass, what difference in their behavior should be noticed?

II.—CURRENT ELECTRICITY.

466. **Definition.**—Electricity in the condition in which it was treated in the last section has generally been called frictional electricity, from the fact that it is most readily developed by friction. But, whether developed by friction, by induction, or by any other method, it always possesses great *intensity*. On this account it is frequently called *high tension* electricity. But one of its most striking characteristics is shown by its remaining for a long time on an insulated body as a charge after the source of excitement has been withdrawn. On this account it is called *static* electricity, the word static meaning *standing* or *resting*.

In strong contrast with this kind of electrical excitement is the electricity produced by a *battery* such as may be seen in any telegraph-office. Electricity thus developed "flows" constantly over a conductor (generally a wire) so long as it is properly connected with the battery, but as soon as this connection is broken all sensible evidence of electrical excitement in the wire, or in anything which may have been connected with it, ceases.[1] The electricity produces its effect while flowing as a current through the wire. On this account it is called *current* electricity. The word current means *running*. In honor of two early experimenters with it, current electricity is frequently called *galvanism*,[2] or *voltaic*[3] *electricity*, or the *voltaic current*. "Galvanic battery" and "voltaic battery" are general terms applied to all forms of battery producing current electricity.

467. **Principle of the Voltaic Battery.**—The origin of the electric current produced by a battery is chemical action between two substances, generally an acid fluid and a metal.

Experiment 181.—Put into any convenient small glass vessel a mixture of 1 part of sulphuric acid to 10 or 20 parts of water. Dip into this a strip of zinc and a strip of copper. A copper cent, fastened to a wire, answers very well for the copper strip. Set the vessel in a light place and examine the liquid near each metal strip. Minute bubbles may be seen rising from the sides of the zinc, but none from the copper. Touch the zinc and copper together above the surface of the liquid, the lower parts remaining immersed. Bubbles will begin to

---

[1] This is not strictly correct when applied to conductors of enormous size, such as an ocean telegraph-cable several thousand miles long, or when the current is made by a very powerful battery.

[2] Aloisio Galvani, Italian, 1737–1798, Professor of Physiology at Bologna, discovered that a piece of copper and a piece of zinc in contact with the nerves and muscles of a dead frog, and with each other, give rise to a current of electricity.

[3] Alessandro Volta, Italian, 1745–1827, discovered that any two metals in contact, and in situation to be chemically acted on, give currents of electricity. He was the inventor of Volta's pile, and of the simple voltaic or galvanic battery.

rise rapidly from the copper plate, and a few will probably continue to rise from the zinc. Separate the metals, and the bubbles stop rising from the copper plate.

These bubbles are hydrogen gas, liberated from the water (which is composed of oxygen and hydrogen) by the chemical union of the zinc with the other elements of the acid fluid. This chemical action is accompanied by the development of electricity, which, when the metals are in contact, or connected by a wire, takes the form of a "current" through the wire, from the copper to the zinc. This chemical action and electrical excitement are inseparable, one undoubtedly dependent on the other. *If the chemical action is stopped, the current ceases; and if the current is stopped, the chemical action ceases.*

468. **Pure Zinc needed.**—The continuous rise of bubbles from the zinc is due to slight traces of some other metals as impurity. The particles of such metals being in contact with the zinc, a number of small "local" currents are established. This action uses up the zinc without giving any compensation in the way of a current over the wire, where, only, we can make use of it. A pure metal by itself is not dissolved in the dilute acid. The surface of the zinc is rendered practically pure by coating it with mercury. Zinc so coated is said to be *amalgamated.*

Experiment 182.—To amalgamate zinc, dip it into dilute sulphuric acid for an instant, and then rub it or slap it with a little muslin bag containing an ounce or two of mercury. Make it shine all over, and repeat Experiment 181, using the amalgamated zinc.

FIG. 268.—VOLTAIC CELL.

469. **The Simple Voltaic Cell.**—The apparatus employed in the last experiment is essentially a voltaic cell. Fig. 268 shows a form of nicely-made cell. The arrows show the direction of the current along the wire

M. The upper extremities of the plates, or of the wires attached to them, are the *poles*, or *electrodes*. The positive and negative are indicated respectively by the signs + and —. We may conceive of electricity being propagated along the wire from the negative as well as from the positive electrode, but the direction on the wire from the *positive* to the *negative* is spoken of as the *direction of the current.*

The wire, the plates, and the liquid between the plates constitute the *circuit*. If all parts of the circuit are conductors of electricity, the circuit is said to be *closed*. When any break exists in the circuit, as would be the case if the wire were disconnected from one plate, or if either plate were taken out of the liquid, the circuit is said to be *open*.

Many combinations are used in the construction of different kinds of batteries. Instead of dilute sulphuric acid, a saturated solution of sulphate of copper—*i.e.*, blue vitriol, or "blue-stone"—may be used. This is the gravity, or Callaud (kal-lō′) cell, shown in Fig. 269. It is the common "local battery" in way-stations on telegraph lines. Gas carbon may be used instead of copper for the positive electrode. Gas carbon and zinc, in an acid solution of bichromate of potassium, forms a very convenient and effective battery for experimental purposes. This is called the "one-fluid bichromate battery." A dozen other single-fluid cells might be mentioned. Zinc is almost universally used as the positive metal,—*i.e.*, the metal acted on by the acid.

FIG. 269.—GRAVITY, OR CALLAUD CELL.

470. **Two-Fluid Cells.**—In most single-fluid cells the hydrogen retards the action. With two fluids this may be obviated. The most powerful of the two-fluid batteries is Grove's. The zinc plate, in the form of a hollow cylinder, or something equivalent, is immersed in dilute sulphuric acid contained in a glass vessel. A vessel of porous earthen-

ware, filled with strong nitric acid, is set in the hollow zinc, and is, of course, surrounded by the dilute sulphuric acid. A strip of platinum, immersed in the nitric acid, completes the cell. The nitric acid supplies oxygen, which unites with and removes the hydrogen that would otherwise surround the platinum. Platinum is used because it is not dissolved by nitric acid. The porous earthenware cup becomes soaked with the acids, and thus conducts the current of electricity, but it does not permit of much mixing of the liquids. Bunsen's battery uses gas carbon instead of platinum. (See Figs. 272 and 273.)

471. **Batteries of Several Cells.**—The term "battery" has been unavoidably used several times in the last few pages. The different arrangements which have been described as producing the voltaic current are properly *cells*. A cell of a given construction gives a current of a definite strength, or, rather, of a definite *electro-motive force*. In order to obtain more electro-motive force than one cell will give, we connect several cells together by means of wires. Such an arrangement is properly a voltaic *battery*. Fig. 272 shows a Bunsen's battery of two cells, and Fig. 273 one of four cells.

It will be seen in Fig. 273 that the zinc of the right-hand cell is connected with the carbon of the second cell, the zinc of the second with the carbon of the third, and so on through the battery. When the first zinc and the last carbon are connected, the circuit is closed and the current flows.

472. **Characteristics of Current Electricity.**—In Art. 466 current electricity is so called because its chief characteristic is that it does its work and makes itself known only as it flows through a conductor. This is true of currents from all ordinary batteries. With an enormous battery of hundreds or thousands of cells a current may be obtained which has an appreciable amount of tension, or tendency to escape; but even this is very low compared with the tension of the electricity on the prime conductor of a working electrical machine. The difference between frictional and

voltaic electricity may therefore be considered a difference in the intensity of the electrical excitement, and voltaic electricity may properly be called electricity of *low tension.* The *quantity* of electricity developed by an ordinary battery is very much greater than that developed in the same time by an ordinary, or even a very large, electrical machine. The constancy and rapidity of the current take a large quantity through a conducting wire in a given time. On good conductors the *rate* of an electric current has been measured at more than 200,000 miles per second. *Electromotive force* is the force with which a current is *urged forward,* and is shown by the ability of a current or a charge to jump through an insulator. The charge of a small electrophorus lid will jump one-fourth of an inch through the air. The current from a thousand Bunsen cells will produce a spark scarcely $\frac{1}{1000}$ of an inch in length. The electro-motive force of current electricity is very small. A number of cells connected, as shown in Fig. 273, increase the electro-motive force in the direct ratio of the number of cells employed. A battery so connected is said to be connected for *intensity* of current, or connected *in series.*

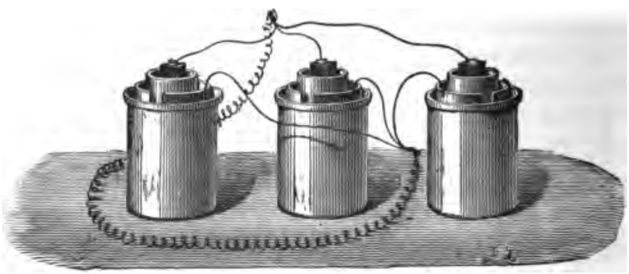


FIG. 270.—BATTERY CONNECTED "SIDE BY SIDE."

When a larger *quantity* of electricity is wanted than one cell will produce, several cells are connected *side by side,* as shown in Fig. 270,—*i.e.,* the zinc plates are all connected with one wire, and the carbon plates with another.

473. **Resistance.**—The electric current encounters *some* resistance in all parts of the circuit. The resistance in the liquid of the battery is very great compared with that in the same length of connecting wire. In a wire of given material the resistance is directly proportional to the length of the wire, and inversely proportional to the area of its cross-section.[1] Different conductors offer different amounts of resistance. When the resistance is considerable, an appreciable amount of heat results. Thin wires of platinum and thin strips of carbon are readily rendered white-hot by the passage of the current. If a copper or iron conducting wire from a battery be cut in one or more places, and pieces of thin platinum wire be stretched across the breaks thus formed, they become white-hot on the passage of a moderately-strong current, and will ignite illuminating gas, gunpowder, or any similar substance in which they may be placed. Such arrangements are very extensively used in lighting the gas in high buildings and in blasting in mines. Platinum offers much more resistance than copper, and the thin wire more than a thicker one would. The thicker telegraph-wires are, the better they will perform their work.

FIG. 271.—EDISON'S ELECTRIC LAMP.

474. **The Edison Lamp.**—The Edison electric lamp consists of a small ribbon of paper-charcoal in the form of a horseshoe, placed between metal tips in a glass globe from which the air has been exhausted. Fig. 271 shows the general appearance of the lamp. A current being passed through from one of the wire ends to the other, the carbon is intensely heated on account of its resistance. As no air is present, it cannot burn away, and so

[1] For instance, a copper wire 200 feet long offers twice as much resistance as one of the same diameter 100 feet long. A wire of a given length and $\frac{1}{20}$ of an inch in diameter offers 4 times as much resistance as a wire of the same length and $\frac{1}{10}$ of an inch in diameter, —*i.e.*, $(\frac{1}{10})^2 : (\frac{1}{20})^2$.

will give a continuous light for many weeks or months. Other incandescent electric lamps are in use, some of which use platinum instead of carbon.

475. **Division of Current.**—If two conductors extend between the plates of a battery, or are so introduced into a circuit that the current may take either, a part of it takes each route, and the amounts are in the inverse ratio of the resistances of the conductors. If, for instance, two copper wires of equal length and equal thickness extend between two points in a circuit, half of the current will follow each. If two points in a circuit be connected by two copper wires, one of which is $\frac{1}{10}$ of an inch in diameter and the other $\frac{1}{20}$ of an inch, and both of the same length, the larger wire will carry $\frac{4}{5}$ of the circuit, and the smaller $\frac{1}{5}$. In this way currents are frequently *divided* for purposes of electric lighting, duplex telegraphing, etc. So a current may be divided into *any number* of parts.

476. **The Ohm.**—The *unit* of resistance is the *ohm*. This is used in designating the amount of electricity required to produce a given effect in electric lamps, telegraph-"sounders," etc. It is nearly the resistance offered by 666 feet of copper wire $\frac{1}{12}$ of an inch in diameter. The resistance of 1332 feet of copper wire $\frac{1}{48}$ of an inch thick would be 32 ohms (2×4^2).

477. **Resistance and Work.**—*The amount of work done by a given current in any part of its circuit is directly proportional to the resistance of that part of the circuit.*

This applies to the amount of light or heat developed in the conducting wire, the strength of magnetic attraction caused by electric currents, etc.

478. The law of the conservation of energy is forcibly illustrated by the heating and lighting effects of the electric current. The burning of the zinc before a blow-pipe, or in a furnace, would produce both heat and light. When it is consumed in a battery the same amount of energy is given out, but in the form of an electric current, which in turn is converted into heat and light, and which, as we shall presently learn, is far more effective than ordinary frictional electricity in producing motion.

479. **Electrolysis.**—In the production of the electric current the water of the battery is separated into oxygen and hydrogen. If the conducting wires be immersed in another vessel of water, so that it will form part of the circuit, this water will also be decomposed, oxygen being liberated from the positive electrode and hydrogen from the negative. Fig. 272 shows the method of illustrating this. As

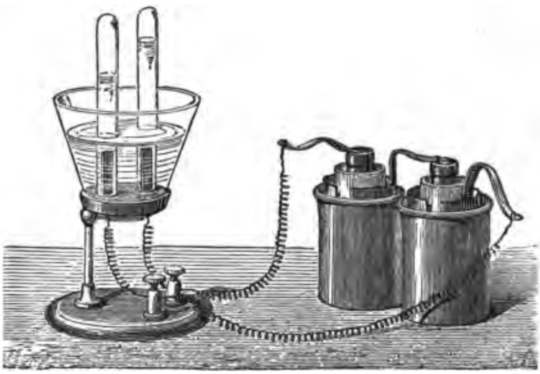


FIG. 272.—ELECTROLYSIS OF WATER.

water is composed of two volumes of hydrogen to one of oxygen, one tube will collect gas twice as fast as the other.

Electro-plating.—The galvanic battery decomposes not only water, but solutions of very many salts of the different metals. The metal of the salt separates in a pure state. The metals are generally *positive* with reference to the other ingredients of a salt, and therefore separate at the *negative* electrode. If we wish something coated or "plated" with silver, gold, or nickel, it is made the negative electrode of a battery by attaching it to the wire from the zinc. It is then dipped into a proper solution of the metal which we wish to plate with. On dipping into the same liquid a plate attached to the positive wire of the battery the circuit will be closed through the solution, the salt will be decomposed, and the metal deposited on the negative electrode. Fig. 273 shows a silver-plating tank in operation. The vessels and other articles which are being plated are all suspended from the rods which are connected with the zinc electrode of the battery. The large square plates suspended from the positive electrode are pure silver,

which is dissolved as the process goes on and keeps the solution of a uniform strength.

Any boy or girl, with very little outlay, may find instructive entertainment in electro-plating. The apparatus here figured may be of

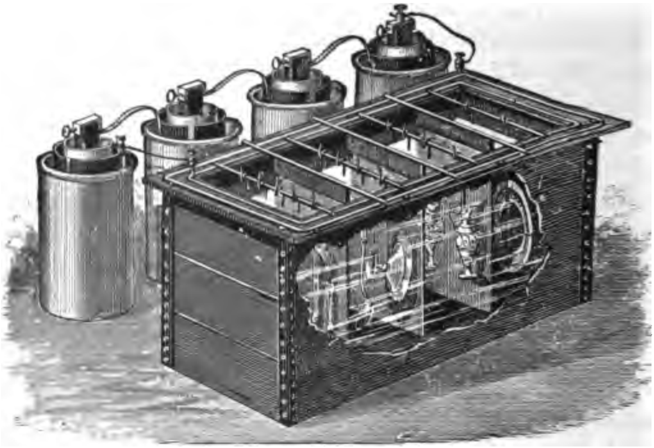


FIG. 273.—ELECTRO-PLATING, WITH BATTERY OF FOUR BUNSEN CELLS.

very much smaller dimensions. The battery may be home-made, a tumbler will hold the plating-solution, and a brass watch-chain or hook, or a copper cent, may be plated. In fact, plating may be done *in the battery*, and that may be easily constructed.

FIG. 274.—SILVER-PLATING A COIN.

Experiment 183.—Put a small silver coin into a dish and pour over it a few teaspoonfuls of nitric acid. (It should be out of doors or in a fireplace, as the fumes are hurtful.) If the acid is strong, put in as much, or twice as much, water. Heat the dish moderately. The coin will dissolve rapidly. When the coin has disappeared, pour the solution into a glass vessel. Add some weak "muriatic" acid, or a strong solution of salt in water, as long as it continues to form white "curds" in the liquid. These white curds are chloride of silver. They will settle to the bottom of the vessel. Pour off the blue liquid, or most of it. Fill up the vessel with water, and pour off several times. This is to remove the copper with which the silver of the coin was alloyed. It is blue in the solution, and when the blue color disappears the chloride of silver is washed enough. It will be necessary now to have about an ounce of cyanide of potassium, a *very poisonous* salt, used to wash

out stains of indelible ink. Dissolve this in water, and add it to the chloride of silver, stirring it round till the white curds are all dissolved. Make this quite weak by the addition of water. A dime will make a half-pint of liquid strong enough for our present purpose. Fill a porous battery cup with this, or, if that is not at hand, a flower-pot with the hole stopped with plaster or putty, or, for a small quantity, the "bowl" of a tobacco-pipe with a plug in the broken-off stem. Set this in any convenient glass vessel, and fill that with dilute sulphuric acid to the level of the silver solution. Put a piece of zinc in the outer vessel, and suspend from it by a wire a small *clean* article to be plated. Take it out and rub it with a cloth after a minute. Repeat several times, each time leaving it in longer. In ten minutes there will be a very good plating, and in an hour or more, depending on the strength of the current, a really thick plating.

480. **Deposit always on the Negative Plate.**—It will be noticed that in the above experiment the article to be plated takes the place of the *copper* plate, while in the methods given in which the battery and the plating solutions are separate the article to be plated is fastened to the wire from the *zinc* plate. This is because *in the battery* the copper is the *negative* plate. The negative plate is that towards which the positive current flows. If the circuit be opened at *any place*, that end of the break *from* which the current flows is the *positive*, and that *towards* which it flows is the *negative*, electrode. In determining where to place an article to be plated, remember that the metal is carried *with the current* in the plating solution, and that the current flows around continuously from copper to zinc in the wire, and from zinc to copper in the battery.

Many interesting variations of the above plating experiment may be tried. Any ordinary soluble salt is decomposed by the voltaic current, the metal going *with the current* to the nearest electrode.

481. **Secondary Batteries.**—We have seen that the current from a battery has the power of separating many compounds into their constituent parts. The reuniting of substances thus separated will, under proper conditions, give rise to a voltaic current opposite in direction to the current which caused the decomposition. This fact is made use of in the construction of what are now (1883) just coming into use under the name of secondary batteries.

Probably the most successful of the secondary batteries is Faure's (fōr), or some one of the very numerous modifications of it. The principle may be understood from a description of the original form, devised by Faure. It consists of two large plates of very thin sheet-lead, each coated with a layer of minium (red oxide of lead), and rolled together into a spiral like a roll of carpet. The sheets are kept separated by rolling in with them soft paper saturated with weak acid. One of these sheets is connected with each of the wires from a battery. Oxygen from the weak acid is liberated on the surface of the lead plate which forms the positive electrode, and hydrogen on the surface of that which forms the negative electrode. The oxygen unites with the coating of red lead on the positive sheet, converting it into a higher oxide of lead. The hydrogen unites with the oxygen of the red lead coating on the negative sheet, and forms water, reducing the oxide of lead to pure lead in a very fine state of subdivision. When all the red lead on one sheet has been converted into the higher oxide, and all that on the other has been reduced to the condition of metallic lead, the secondary battery is said to be "charged." If, now, the wires are disconnected from the charging battery and brought into contact with each other, a current will be found to pass through them, and, as said before, it flows backward with reference to the direction of the primary current, or from the oxidized to the deoxidized plate.

482. Energy of Secondary Battery.—The total amount of energy given out in the discharging of a secondary battery is, of course, equal to that consumed in charging it, and in practice this may nearly all be made available. The total "quantity" of an electric current, or of the energy of a given current, is equal to the amount for any unit of time multiplied by the time during which the current flows. A secondary battery may be charged by a small battery working for a considerable length of time, and may be discharged in a powerful current flowing a proportionately short time. This feature renders it admirably adapted to electric lighting, or to the driving of electric motors, where such use is needed for but a small part of each day. The secondary battery is also very much lighter than a primary battery required to give a current of equal intensity. It is thus adapted to use where the size and weight of a large

battery are an objection. It has already been applied to driving road-carriages and to lighting steamships and railway-cars.

III.—ELECTRO-MAGNETISM.

483. **Oersted's Discovery.**—About the year 1820, Hans Christian Oersted (ur'sted), Professor of Physics at the University of Copenhagen, discovered that a wire through which a voltaic current is flowing has the power of deflecting a magnetic needle out of the meridian. This discovery at once established the connection between electricity and magnetism, and laid the foundation for the many useful applications of "electro-magnetism" which we now see all about us. Oersted also discovered that the conducting wire of a battery is magnetic while the current is passing.

484. **Direction of Deflection.**—The *direction* in which a needle is deflected by the voltaic current may be readily remembered by the following rule:

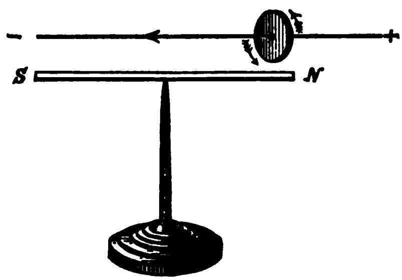


FIG. 275.—SHOWING DIRECTION OF NEEDLE'S DEFLECTION.

Consider the deflecting force to rotate around the conducting wire as the thread winds around a screw, moving from the head towards the point of the screw,—that is, rotating as the hands of a watch turn. When the current is passed near a magnetic needle, and parallel with it, the north-pointing end of the needle is turned from its position in the direction of the action of such a force, whether eastward or westward, or upward or downward.

For instance, suppose a current pass on a wire parallel to a needle, from the north to the south, if it pass above

the needle, the north-pointing pole will be turned eastward; if it pass beneath, the same pole will be turned westward; if at the same level on the right-hand side, the north pole will be raised; if on the left-hand side, it will be depressed.

In Fig. 275 the arrow-head, as well as the + and — signs, indicates the direction in which the current flows over a wire, and the arrows on the wheel show the direction of rotation of the magnetic force. In whatever position the wire is held, imagine the circumference of this wheel to strike the *north* end of the magnet and carry it in the direction of its own motion.

485. **The Amount of Deflection** of a given needle depends on the total effective strength of the current. A given current may multiply its effect on the needle by passing several times. If one current pass above a needle from north to south, and another pass beneath it from south to north, the two currents will tend to deflect the needle in the same direction, and the effect will be a double deflecting force. The same result is obtained when the wire is bent so that the *same* current may pass in one direction above the needle, and in the other direction under it. The result is intensified by so coiling the wire as to make the current pass many times around the needle. This principle is made use of in the construction of the *galvanometer*, or instrument for detecting and measuring the galvanic current.

FIG. 276.—GALVANOMETER.

486. **Galvanometer.**—Fig. 276 represents a common form of galvanometer. It has a double, or *astatic* needle,—*i.e.*, two magnetic needles so arranged that they neutralize each other's tendency to stand north-and-south,—suspended by a thread of "unspun" silk. The graduated circle which lies on the coil of wire, and just

under the uppermost needle, indicates the amount of deflection.

487. **The Electro-Magnet.**—The galvanometer needle is never deflected more than 90 degrees, or till it stands at right angles to the direction of the electric current. A comparatively feeble current will turn a needle nearly at right angles to its course, indicating that the natural position of magnets is *across* the direction of electric currents. Not only do currents tend to turn magnets into this direction, but they *magnetize* iron or steel bars near which they pass. A magnet formed by passing a voltaic current across a bar of iron is called an *electro-magnet*. It is *magnetic only while the current passes.*

488. **The Helix.**—A current crossing an iron bar only once makes a very feeble magnet of it. If the conducting wire be covered with an insulating cover of wax, india-rubber, silk, or even cotton, it may be wound many times around a bar, as cotton is wound on a spool. As many currents multiply the effect of one, there is scarcely a limit to the power of electro-magnets thus made. Fig. 277 shows a horseshoe electro-magnet. A layer of wire wound from end to end or over a considerable part of the length of a bar is called a *helix*. Several layers, such as are shown on each arm of the horseshoe in the figure, constitute a *coil*.

Experiment 184.—Procure of a dealer from two to four ounces of very fine covered copper wire. Wind it neatly around an iron bar as large as an ordinary lead-pencil, making several layers. Connect the free ends of the wire with any simple battery, and experiment with the electro-magnet thus formed. Dip it into nails, and, when it is loaded, break the circuit. Notice that some of the nails incline to stay on after the current is stopped. This is on account of the residual magnetism which iron is apt to exhibit after having been once magnetized. Try the poles of the electro-magnet with a magnetic needle, and notice the direction of winding of the coil of wire as looked at from each end. Refer to rule for deflection of needle by the electric current, and notice that the same rule holds here.

As electro-magnets are much more powerful than steel magnets, they are mostly used in magnetizing steel bars. Fig. 278 shows the

method of operation. Of course, reference to the direction of winding indicates the respective poles of the electro-magnet.

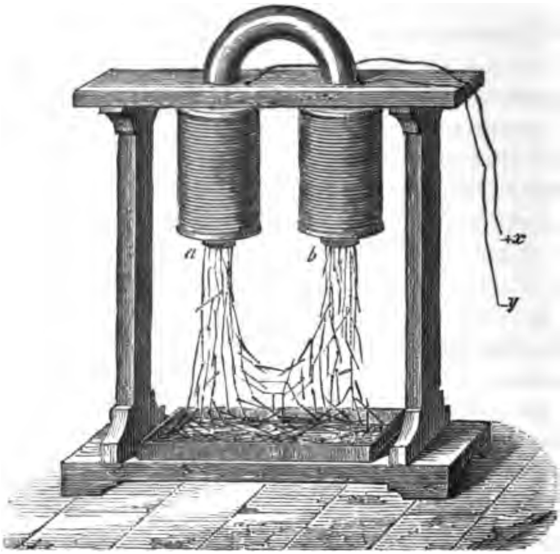


FIG. 277.—ELECTRO-MAGNET.

489. **The Helix a Magnet.**—A helix, or coil carrying a voltaic current, not only communicates magnetic properties

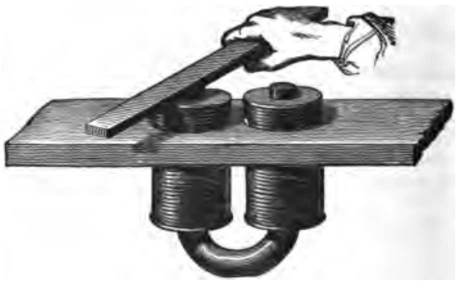


FIG. 278.—MAGNETIZING STEEL BAR.

to the bar of iron in the middle, or "core," but is itself a magnet. It attracts iron, is attracted and repelled at the

different ends by the poles of a steel magnet, and, if properly suspended, arranges itself in the magnetic meridian, the hollow centre taking the north-and-south direction. If a strong steel magnet be placed directly under a helix suspended horizontally, the helix assumes the direction of the length of the magnet, the convolutions of the wire being *across* its length. This shows a *mutual action* between electric currents and magnets, and that they are naturally at right angles to each other.

490. **Electric Currents in the Earth.**—The north-and-south tendency of magnets may be due to electric currents flowing westward around the earth. In cases of unusual fluctuation of the compass, electric currents have frequently been detected, in such direction as they should flow, to account for some of the observed phenomena. The existence of currents to account for all the ordinary phenomena of the magnetic needle is not established, but there are strong reasons for believing that they do exist.

491. **Magnetic Storms.**—Telegraph-operators frequently report electrical or "magnetic storms," which are sometimes of considerable extent and cause them much inconvenience. They are not necessarily accompanied by wind, rain, snow, or any other of the phenomena ordinarily included in the term "storm," but are simply disturbances in the electrical or magnetic condition of the earth and the air. Magnetic needles move backward and forward through several degrees, telegraph-wires refuse to carry the battery currents with any regularity, and fine displays of aurora borealis are witnessed. The aurora may not be seen where the disturbances are felt, but it is sure to be visible somewhere within a few thousand miles of the centre of greatest disturbance.

As illustrations of the effect of such storms, we quote from Chicago dispatches an account of the effect there of one which occurred in the autumn of 1882: "The storm seemed to go in successive negative and positive waves, alternately neutralizing the currents on the telegraph lines, or increasing their intensity to such a degree as to burn things up. The 'switch-board' at Chicago was on fire a dozen times, and half a dozen keys of instruments were melted. The atmospheric electricity on one of the country wires had such power as to suffice to keep an electric lamp burning. Fully two-thirds of the sky is ablaze to-night with auroral light of many colors, a rare phenomenon in this region." At Nashville, during the same storm, the telegraph

lines "were worked at intervals solely by the auroral current. The needle in the galvanometer oscillated in a most eccentric manner, varying as much as 80 degrees." This storm was wide-spread, extending over all the northern half of the United States and north and east as far as telegraph lines extend. A dispatch was sent from Bangor, Maine, to North Sydney, Cape Breton, a distance of 700 miles, without a battery! The disturbance to telegraphic communication was greatest on lines extending east and west, and this was largely removed by using wires for the whole circuit instead of employing the earth for the conductor in one direction, as is usually done.[1]

492. **Applications of Electro-Magnetism.** — As electromagnets are magnetized and demagnetized by simply closing and breaking the circuit which carries the current through the coil, they find many useful applications. Engines have been made in which armatures are attracted in alternate directions by different electro-magnets acting at alternate moments. Such an armature may be made to carry with it a rod to turn a crank, or, in some other manner, to give motion to ordinary machinery. For very light work an engine of this kind may be used to advantage, but the cost of maintaining a powerful battery is too great to admit of its economical use where great power is required and where steam or water can be conveniently supplied.

493. **The Electric Telegraph.**—The one successful and useful application to which electro-magnetism has been put during the past forty years is telegraphing. The word "telegraphing" means writing at a great distance, and a "telegraph" is any instrument by which a person at one place can make signs which may be read at another place some distance away.

494. **History of the Telegraph.**—Frictional electricity was known to the ancients before the Christian era, but conduction and insulation appear not to have been discovered till 1729. Very soon

[1] Some connection seems to exist between these storms and the condition of the sun. (See Sharpless and Philips's Astronomy, p. 58.)

after the discovery of conduction, and the classification of bodies as conductors and insulators, plans were devised for carrying conducting wires on insulating supports and transmitting through them charges of frictional electricity, which should be sent in an order agreed upon to represent letters or words. Systems arranged on this principle were never very satisfactory. One of the best employed a separate wire for each letter of the alphabet, each wire being supplied with a delicate electroscope. The person sending the message touched the wires to the conductor of an electrical machine in such order as to spell out the message to be transmitted, and the person receiving it watched the order of divergence in the electroscopes, and so read the message. This system was costly and cumbrous, and it could be successfully operated only through short distances (20 or 30 miles), so that it never came into general use.

Voltaic electricity was discovered about 1792. Oersted's discovery of the deflection of the magnetic needle was made in 1820, and was soon applied by Wheatstone[1] and others to successful systems of telegraphing.

495. **The Morse Telegraph.**—The introduction of the electro-magnet as an essential feature of the telegraph dates back to about 1836, when Samuel F. B. Morse[2] invented the electro-magnetic telegraph now in general use in civilized countries. His original device consisted of a register (Fig. 279) for receiving the message, and a key (see Fig. 280) for transmitting it. The register is easily understood from the figure. The current from the line wire passes through the coils of the electro-magnet, which is thus rendered magnetic, and draws down the armature. This elevates the point shown on the opposite end of the lever. The paper is drawn at a uniform rate between the rollers by the action of the weight under the table. When the point is pressed against the paper it describes a straight line, whose length is proportional to the time the point is held there. This is determined by the operator at the distant station, who alternately depresses and elevates his key. While he holds the key down the current passes, the armature is held down, and the point is pressed up. Long and short dashes (called respectively "dashes" and "dots") and vacant spaces are thus recorded in succession on the strip of paper,

---

[1] Charles Wheatstone, English, 1802–1875, professor at King's College, London.

[2] American, 1791–1872. The inventor of the form of telegraph-receiver in common use.

and, as a definite group of these dots and dashes represents each letter, figure, and other mark used, the receiving operator is able to inter-

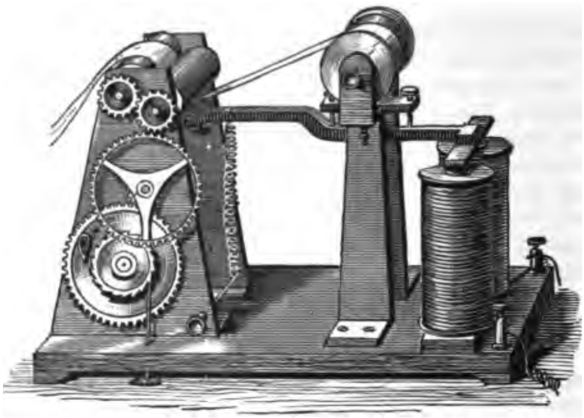


FIG. 279.—TELEGRAPH-REGISTER.

pret them. The accompanying line of dashes and hyphens represents the appearance of such a message. The letters above them are intended as a translation, for the benefit of the readers of this book.

W i l l c o m e a t t e n A M .

The striking of the lever against the screws which regulate the distance of its motion makes an appreciable sound, and a certain different combination of these is used to call the attention of each particular operator on a given line.

Soon after this system came into use, operators discovered that they could read the *messages* as well as the office-call by the click of the lever against the screws, and the paper was dispensed with. A new form of instrument, known as the *sounder*, now takes the place of the register in most telegraph-offices. Its general structure may be understood from Fig. 280. The lever is drawn down by the electro-magnet, and strikes against a solid metal piece, making a loud sound. A spring is so attached to an arm connected with the lever that it instantly raises the lever on the breaking of the current.

When a telegraph line is long, the resistance of the wire renders the current feeble, so that the sounder is not operated with sufficient force to be satisfactory under all circumstances. To remedy this, a *local battery* is introduced at each station to operate the sounder at

that station. The circuit of this battery (the "local circuit") is opened and closed by a *relay*, which in turn is operated by the feeble current of the line-wire. The "relay" is a very delicate electro-magnet, operating a lever whose end is made to strike against a metal piece and thus close the local circuit.

Fig. 280 represents, in vertical section, a Morse telegraph-station, such as may be seen in almost any town or at almost any railroad-station. The student will please trace out the office and action of each piece of apparatus. The key, the sounder, and the relay may be supposed on a table, and the local battery under it. The wire of the main line is seen entering at one side and leaving at the other. The key must be kept "closed" at all times, except in the particular office on a line from which a message is, at the time, being sent. The current in Fig. 280 we will suppose enters at the left, passes through the key, and by the wire to the relay, around the coils of the electro-magnet in the relay, and out at the right, going in the same way *through all the offices which are in the main-line circuit.* When no message is traversing the line, the current is continuous, the cores of all the relays are magnets, and the armatures are all held against the opposing anvils. This closes the local circuits and holds down the levers of the sounders. When a message is to be sent from any office on the line to any other office, the operator in the sending office opens his key. This breaks the circuit, stops the current, and demagnetizes the relay, whose spring pulls back the armature. This in turn breaks the local circuit and demagnetizes the sounder, whose lever is raised by its spring. This is the condition of things shown in the figure.

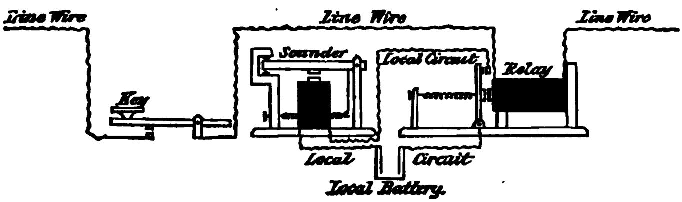


FIG. 280.—DIAGRAM OF MORSE TELEGRAPH STATION.

The sender then operates his key by pressing it down and raising it at certain intervals. The currents thus sent operate on the relay situated in each office of the line, and its armature vibrates, keeping time with the motions of the sender's key. This acts as a key for the local circuit, and a succession of currents is sent through it, operating the sounder. Thus it will be seen that a message sent from any one

station to any other station may be read at all the stations in the main circuit. The sending operator even reads his own message.

496. The Earth used as a Conductor.—In all ordinary telegraph and telephone lines the earth is used as a conductor in one direction, and but one wire is employed. Most lines of telegraph have a battery at each end, the positive electrode of one battery and the negative of the other being connected with the same wire. The other electrode of each battery is connected with a "ground-wire," which is attached to a metallic plate buried in moist earth.

497. Duplex and Quadruplex Telegraphy.—The simple Morse system, just described, is very reliable, but a given wire can transmit only one message at a time. Various arrangements have recently been devised by which a wire may be made to convey one or two messages *each way* at the same time without conflict. The former is known as the *duplex* system, and the latter as the *quadruplex* system. A complete explanation of them would take us beyond the limit of this work.

The art of telegraphy is advancing very rapidly. Mechanical arrangements for transmitting are successfully employed, and automatic arrangements for receiving and for retransmitting if desired. The simple Morse system was a marvel of completeness and rapidity. A good operator can send or receive 30 or 40 words per minute,—as fast as a rapid penman can write. This was the capacity of a single wire until recently. With a combination of the latest inventions the feat has been accomplished of transmitting 1500 words between New York and Boston over the same wire in one minute.

498. Ocean Cables.—On land lines the line-wire, even if very long, is charged and discharged nearly instantly, and the current is no appreciable length of time in traversing it. Ocean cables, being laid under water, must be surrounded by an insulator. Gutta-percha is used. The arrangement then resembles a Leyden jar, the conducting wire representing the inside coat, and the water the outside coat, while the gutta-percha acts as the glass. To *charge* this requires some time, and to discharge it requires as long. In the cable between Ireland and Newfoundland this amounts to a total of six seconds. On this account special instruments are required for sending and receiving messages over ocean cables.

499. Electric Clocks.—The electric current is frequently used to propel or regulate clocks. The pendulum of a standard clock is made to operate a key, which opens and closes a circuit including all the clocks to be regulated. These may be distributed over a large build-

ing, or a town, or along a railroad line. The interrupted current passes through an electro-magnet in each clock. The armature, moving in exact unison with the beats of the standard clock, either operates on a ratchet-wheel and communicates motion to the clock, or regulates the swinging of a pendulum. In either case all the clocks will keep exactly together and with the regulator.

500. **Thermal Electricity.**—If a bar of antimony (A, Fig. 281) and a bar of bismuth, B, be soldered together at one end, and the junction be moderately heated, and wires at the other end be connected with the coils of a galvanometer, an electric current is found to exist flowing from the antimony through the wire to the bismuth, and from the bismuth across the heated junction to the antimony. If the junction be cooled instead of being heated, a current is established in the opposite direction.

If a large number of such bars be joined together in series, as shown in Fig. 282, a very slight amount of heat-

FIG. 281.—THERMO-ELECTRIC PAIR.

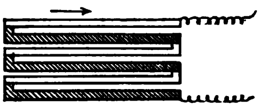


FIG. 282.—PRINCIPLE OF THERMOPILE.

ing or cooling of the junctions at one end makes an appreciable current, the current always flowing at the warmer junctions from bismuth to antimony, and at the cooler from antimony to bismuth. The same effect, in a less degree, is produced by substituting other metals for the antimony and bismuth. Two metals so arranged are called a thermo-electric pair, and a combination of several (usually twenty-five to one hundred) such pairs constitute a *thermopile.* When connected with a galvanometer it is known as the *thermo-multiplier*, one of the most delicate of thermometers.

501. **Induced Currents.**—If a coil of wire, around which a battery current is flowing, be introduced into a larger coil (see Fig. 283), a galvanometer shows that *while the first coil is moving into the second* a current flows in the outside

coil. On *removing* the inside coil, a current flows in the outside coil. This is an *induced* current, and it *lasts only while one coil moves towards or from the other.* The coil connected with the battery is called the *primary* coil, and the

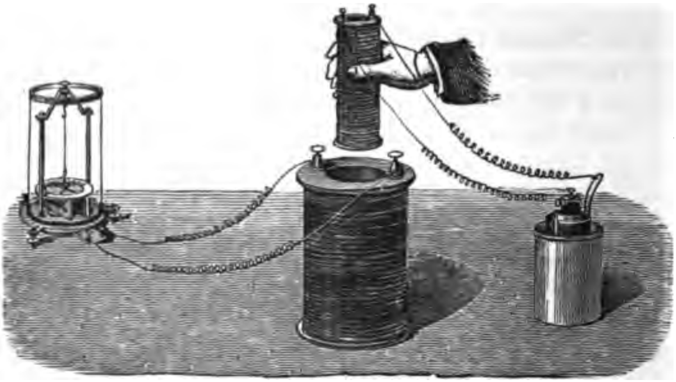


FIG. 283.—PRIMARY AND SECONDARY CURRENTS.

other the *secondary* coil. Every motion of the primary coil *towards* or *into* the secondary coil produces a current in the secondary coil *opposite* in direction to that in the primary; and every motion of the primary *from* or *out of* the secondary produces a current in the secondary in the *same* direction as that in the primary.

If the primary coil be dropped into the secondary and allowed to remain, no induced current is noticed after the primary coil is inserted, so long as the primary current is *constant.* Any *increase* in the strength of the primary current induces an *inverse* current (*i.e.*, opposite in direction to its own) in the secondary coil, and any *decrease* in the strength of the primary current induces a *direct* current in the secondary. If the primary circuit be alternately closed and opened while the coil remains in the secondary, it is found that every time the circuit is *closed* an *inverse* momentary current is induced in the secondary, and whenever it is opened a *direct* momentary current is induced. These

last currents have a great electro-motive force, will jump a considerable distance through air, and exhibit other properties of frictional electricity. They will be more fully treated of in Art. 513.

If, instead of a primary coil, a *magnet* be used, its approach induces a current in one direction, and its removal induces a current in the opposite direction. If an iron core be placed in the secondary (Fig. 284), opposite cur-

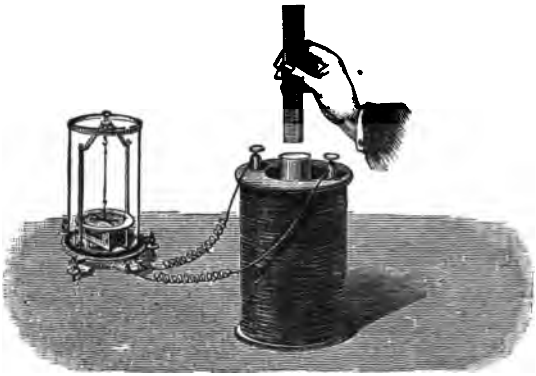


FIG. 284.—CURRENT INDUCED BY MAGNET.

rents are induced by the approach and withdrawal of either pole of the magnet. These currents are stronger than those induced by the same magnet in the same coil without the iron core. This is because the magnet acts by induction on the iron and makes it a magnet (Art. 412). If, now, the magnet be placed in the coil, and the piece of iron be suddenly moved towards it and away from it, the same alternating currents will be induced, the iron acting as a magnet. If these currents, instead of being passed through a galvanometer, as shown in Fig. 284, be passed through a second coil surrounding a magnet, they vary the strength of the magnet, the current in one direction adding to its strength, on the principle of the electro-magnet, and that in the other direction taking from it.

502. The Telephone.—The last article explains the principle of the Bell telephone, which, although first publicly exhibited at the time of the Centennial Exhibition in 1876, is now in very extensive

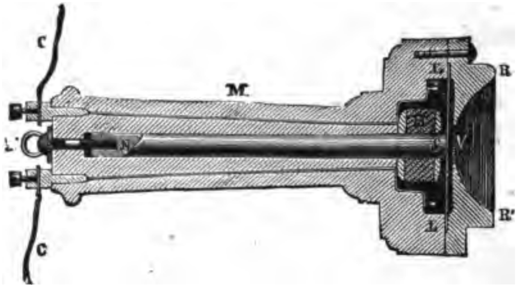


FIG. 285.—SECTION OF BELL TELEPHONE.

use throughout the civilized world. Fig. 285 shows the instrument in section. NS is a steel magnet. B is the coil of fine wire, whose ends are connected by the binding screws with the line-wires CC. LL is a sheet of very thin iron, called the *diaphragm*. The whole is enclosed in a neat rubber tube, M, and supplied with a mouth-piece (and ear-piece), RR′. To send a message, the operator speaks into the mouth-piece. The sound throws the air into vibration, and this in turn communicates its motion to the diaphragm. The diaphragm, being so near the magnet, is polarized by induction. As it is pushed towards the magnet by the sound-waves it induces a current in one direction in the coil of wire, and as it recedes it induces a current in the opposite direction. These alternating currents, agreeing in frequency with the sound-waves made by the operator's voice, are propagated through the wires to the distant station, and are there received by an instrument exactly similar to the transmitting instrument. Of these rapidly alternating currents, those in one direction strengthen the steel magnet, and those in the other direction weaken it. It thus exerts a varying amount of attraction on the diaphragm and causes it to vibrate, the vibrations keeping time with the alternations of the current, which in turn keep time with the vibrations of the transmitting diaphragm, and as this keeps time with the vibrations of the operator's voice, the sound of his voice is reproduced at the distant station. Fig. 286 represents the two terminal stations of a telephone line, connected. The letters correspond with those in Fig. 285.

There may be any number of telephones on the line, and the cir-

cuit may be completed by using ground-wires, as with the telegraph. There should be two instruments at each station, one for the operator to hold to his ear and one to his mouth. A battery current is sent through to an alarm-bell (Art. 505) to call attention when a message is to be sent.

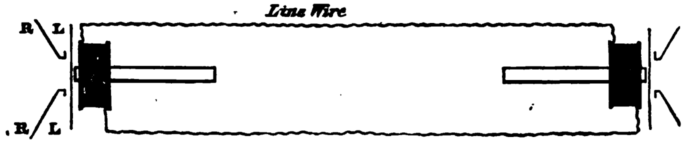


FIG. 286.—DIAGRAM OF BELL TELEPHONE LINE.

503. The telephone is a beautiful illustration not only of electro-magnetic induction, proving the close connection between electricity and magnetism, but also of the transformation of energy, and of the correlation of the physical forces (Art. 83). The sound-waves set the diaphragm into vibration; the force of its motion, by reaction on the magnetic pole, appears as the electric force in the wire; this is transformed into magnetic force at the other end of the wire, which is made known to us by the vibration of the second diaphragm, conveyed to our ear through the medium of the air, just as it would have been had our ear been near enough to catch the vibrations in the air produced by the speaker's voice!

504. The Telephone Current Feeble.—The telephone current is very feeble. It has been estimated that the force represented by the amount of heat required to raise one gram of water one degree Centigrade would be sufficient to impress 10,000 words on a Bell telephone. This would be more than twenty pages of the large type of this book.

Many wonderful and useful recent inventions are applications of feeble currents thus induced in what might be termed secondary coils, or of the slight changes in strength of primary currents.

505. The Alarm-Bell.—The attention of the receiving operator of a telephone message is called by a bell similar to those employed in burglar- and fire-alarms, and in hotels and other large buildings as call-bells. The operation of such a bell will be readily understood from Fig. 287. The current passes in at one of the "binding screws," AD, and out at the other, traversing the coils of the electro-magnet. The core is thus rendered magnetic, and the armature, B, is drawn forward, causing the hammer, M, to strike the bell. The current

on its way from A to D passes up through the armature, B, and down through the spring, R. When B is drawn forward, contact with the spring, R, is broken, and the current ceases. The core is thus de-

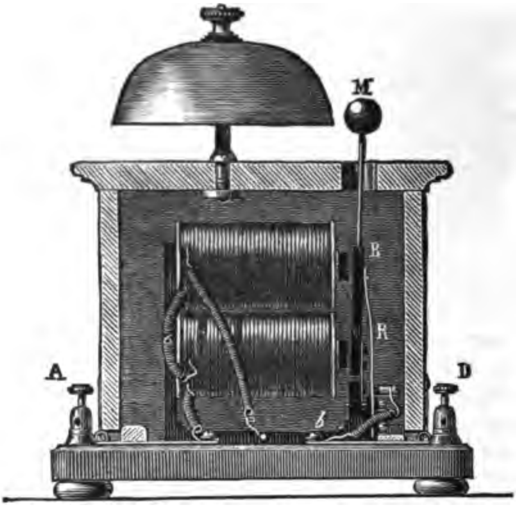


FIG. 287.—ELECTRIC BELL.

magnetized, and B is released and thrown back by the small spring at the bottom. This again closes the circuit, and the operation is repeated, in most cases several times in a second, as long as the current is sent.

IV.—MAGNETO-ELECTRICITY AND DYNAMO-ELECTRIC MACHINES.

506. **Currents produced by Magnetism.**—Referring again to Art. 501, we find that the approach of a magnetic pole to a coil, and the withdrawal of it from the coil, induce currents in the coil. If the pole be stationary, and the coil (better with an iron core) be moved, the same currents result. This is Faraday's discovery, made in 1831, and he showed that such currents result in all conductors which move in the magnetic field (the space strongly influenced by the magnet) in any direction other than parallel to the

lines of force (Art. 420). A current so developed possesses the properties of voltaic electricity. It is now largely employed for producing the electric light, and for driving electric motors. A description of the apparatus used for generating it will, therefore, be in place here.

507. Clarke's Machine.—One of the original forms of magneto-electric machine is shown in Fig. 288. Its operation is plainly indi-

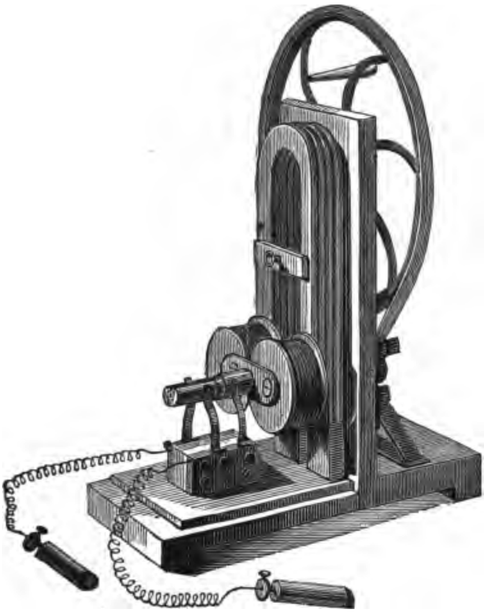


FIG. 288.—CLARKE'S MAGNETO-ELECTRIC MACHINE.

cated. The two coils of wire with soft iron cores are made to rotate rapidly about the horizontal axis, so that each one is brought opposite each of the magnet's poles in each revolution. As each coil approaches each pole, a current is generated in it in one direction, and as it recedes, a current is generated in the opposite direction. These currents are conveyed to the wires, and, on account of their intermittent nature, they produce a peculiar shaking or "shocking" sensation on passing through the body. The machine here shown is intended

for giving such shocks. The currents may either be allowed to flow through the wires in alternate directions, or, by means of a mechanical device known as a *commutator*, all the positive currents may be delivered to one of the wires, and all the negative to the other, thus making the currents all "flow in the same direction."

508. **History of Magneto-Electricity.**—By employing a large number of powerful horseshoe magnets and a larger number of revolving coils, machines on this plan were made, under the supervision of Faraday and others, which gave currents of sufficient intensity to be used in electroplating, electric lighting, etc. In 1866 it was discovered by Wilde that the current from a large magneto-electric machine, conveyed around the coil of an electro-magnet, endued it with a magnetic strength far greater than that of the *whole series* of steel magnets used to generate the current. A fresh and larger armature[1] was made to revolve before the poles of the electro-magnet thus formed, and from this armature a very powerful current was obtained. This in turn was made to magnetize a second electro-magnet, and from an armature revolving in front of its poles a current was obtained far exceeding anything previously known.

509. **Dynamo-Electric Machines.**—The next step in the manufacture of magneto-electric machines, or, as they are now commonly called, *dynamo-electric* machines, consisted in *raising the power* of an electro-magnet *by its own induced currents.* When the iron core of an electro-magnet has been once magnetized, it retains for a long time a slight amount of residual magnetism. An armature revolving before the poles of such an electro-magnet has very feeble currents developed in it. These are carried through the coil of the electro-magnet, increasing its strength. This increases the current in the armature, which further strengthens the power of the electro-magnet, and so the

[1] The "armature" in magneto-electric machines is the whole series of the revolving coils with soft iron cores.

current and the magnet strengthen each other, the limit being fixed by the power of the machine which gives rotation to the armature. The armature with the current flowing in it, and the magnetic pole which produces the current, repel each other as similar magnetic poles do; hence the necessity of force to overcome this repulsion. Of course, the stronger the magnet and the stronger the current, the more force will be required; and, as there is no limit to either, the power of the driving-engine decides the strength of the current. The current which thus excites the electro-magnet passes, after leaving it, over conducting wires wherever wanted, and becomes the current of the machine. If this current is made to flow through the armature of another similar machine, it rotates the armature backward, by virtue of the repulsion above alluded to, and the force with which it rotates is equal to that applied to the first machine, except that which appears as heat, caused by the resistance of the conducting wire, friction of parts, etc.

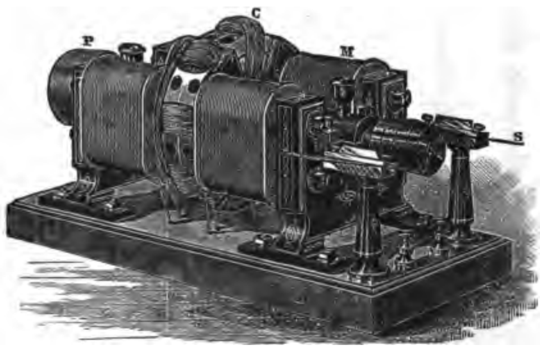


FIG. 289.—BRUSH'S DYNAMO-ELECTRIC MACHINE.

Fig. 289 represents the Brush dynamo-electric machine, one of the many patterns constructed on plans essentially as described. It is selected for illustration here on account of its very extensive use in this and other countries for electric illumination.

The armature, which is represented between the large electro-

magnets, M, is rotated by the pulley-wheel, P. The currents generated in the coils, or "bobbins," C, of the armature are made to flow in the same direction by means of a commutator. They are then collected by the contact-springs, S, and conveyed through the wires surrounding the electro-magnets, M, and extending wherever the current is wanted.

510. The Electric Arc.—As previously stated, current electricity does not jump a break of any appreciable width in the conducting wire. Whenever a circuit is broken, however, a momentary spark is noticed at the break, unless the current be quite feeble. This spark is due to a few of the particles of the conducting wire being carried over in an attempt to keep up the current. They are rendered incandescent because of the increased resistance (Art. 473) of their small number. If two pieces of gas carbon, placed end to end, be introduced into the circuit of a powerful battery, or of a dynamo machine, and then gradually separated to the distance of about a half-inch, particles of incandescent carbon travel across the break, producing the most brilliant of artificial lights. The light-giving area has the form of a crescent, and on this account is called the electric *arc*. A light so produced is called an *arc* light, to distinguish it from the *incandescent* lights, of which the Edison lamp, previously explained, is a type.

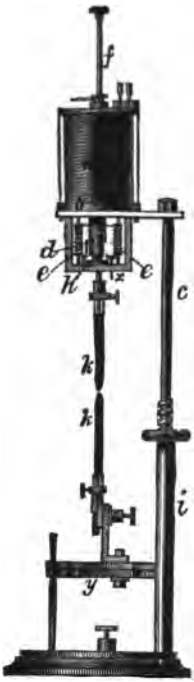


FIG. 290.—BRUSH'S ELECTRIC LAMP.

511. The Brush Electric Lamp—. There are many forms of lamp for producing the arc light. Fig. 290 represents the Brush lamp. The light is produced in the space between the two carbons, *kk*. One of the conducting wires is connected with the lower carbon by the binding screw shown, and the other wire is so connected that the current

passes through the coil, *a*, and then to the sliding-rod, *f*, which holds the carbon at its lower extremity. When the current is turned into the lamp, the points, *kk*, are together. The current passing magnetizes the iron core, *d*, of the coil, *a*, and draws it into the coil, thus separating the carbons and producing the light. As the carbons are drawn farther apart, the resistance increases, the current becomes more feeble, the coil, *a*, becomes weaker, and stops raising the core, *d*. The strength of the current and the distance of the carbons thus maintain a constant balance. When the current is shut off from the lamp the carbons fall together again. The carbons are gradually consumed. The mechanism below the coil, not well shown in the figure, is for lowering the sliding-rod, *f*, through the iron core, *d*, so that the carbons may be kept at a uniform distance from each other, no matter how long or how short they may be.

512. Methods of Electric Illumination.—Of course any judicious combination of current-producing machinery and lamp will produce the electric light. For street illumination, railroad depots, etc., the dynamo machine and the arc lamp seem well adapted. For houses, the incandescent light is by far the more satisfactory, not having the flicker of the arc light. In large communities a dynamo machine will furnish a current economically. For isolated families, the hope for a satisfactory electric light seems to rest on the perfecting of the secondary battery (Art. 481).

513. The Ruhmkorff Induction-Coil.—As stated in Art. 501, currents of great electro-motive force are generated in a secondary coil at the instants of starting and stopping the current in the primary coil. These currents not only possess the characteristics of frictional electricity, but the discharges may be obtained from such an induction-coil with much more uniformity than from an electrical machine, and the coil is not perceptibly affected by atmospheric conditions. Such being the case, a description of the Ruhmkorff[1] coil, and of some of the effects which may be produced by it, is here inserted.

Fig. 291 gives a general view of the coil, mounted. The current from the battery enters by the binding-posts, AA′. C is the commutator for reversing the current so that it may be made to flow

[1] German, settled in Paris; has gained distinction from this form of induction-coil.

either way through the primary coil at pleasure. At *r* is seen the iron core of the primary, and a small section of the primary coil

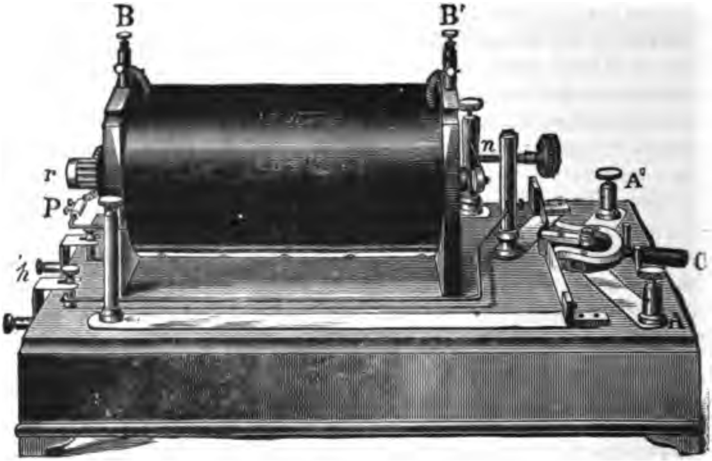


FIG. 291.—RUHMKORFF'S INDUCTION-COIL.

may be seen. The secondary coil is much larger than the primary, and forms the large cylinder. The ends of the wire forming the secondary are seen at BB′. The primary circuit is automatically closed and opened by the "break," *n*. The current traverses the post at the left of *n*, then by way of the spring and screw to the right-hand post, then by way of the wire, etc. In the figure the circuit is closed. The iron core, extending entirely through the coil, is thus magnetized, and attracts the disk on the spring, *n*, drawing it away from the end of the screw and breaking the current. As soon as the current is broken, the spring flies back against the screw, thus starting the current again. The core again attracts the disk, and so the current is made and broken several times in a second.

As previously stated, the *breaking* of the primary current induces a *direct* current in the secondary, and the *making* of the primary current an *inverse* current in the secondary. This may be remembered by supposing the direct current in the secondary to be a momentary continuation of the force of the primary current after it is broken, and the inverse current to be a reaction on the secondary wire by the starting of the primary current, just as a horse in starting a heavy load tends to slip backward. The *direct* current has very

much more electro-motive force than the inverse current has; in fact, with ordinary coils the effect of the inverse current is not noticed; it is the direct current, or that produced when the primary current is *stopped*, that produces the results which we witness. The *positive* electrode of the secondary coil is that *from* which the *direct* current flows, and the *negative* electrode is that *towards* which the direct current flows. To give the direct current its maximum effect, the break of the primary circuit must be made instantaneously. Though we adopt a mechanical device which accomplishes this result, it is found that an "extra current"[1] lingers for a sensible length of time in the primary coil and interferes with the intensity of the secondary current. To correct this a condenser (Art. 453) is connected with the primary circuit. This consists of several sheets of tin-foil, separated by varnished paper, placed in a drawer in the base of the coil. In the figure the connections with the condenser are shown at *pp*. The sheets are connected alternately with the parts of the conducting wire towards the respective poles of the battery. When the current is broken, the extra current spends itself in charging this condenser, which immediately discharges itself through the wire in the opposite direction, and thus assists in exciting the secondary current.

The effectiveness of the Ruhmkorff coil increases with the length of the wire in the secondary coil. As those layers of wire which are nearest to the primary are most powerfully affected, it is desirable to have all as near as possible. For this reason the secondary is of very fine wire, not more than $\frac{1}{100}$ of an inch in diameter. The best coils contain several miles of such wire, from 20 to 50 being a not uncommon quantity. The great coil of William Spottiswoode contains 280 miles in the secondary coil. It forms a cylinder 37½ inches long and 20 inches in diameter, and will give a spark 42½ inches long. An induction-coil about 6 by 2 inches, and giving a half-inch spark, is a very convenient apparatus for administering electric shocks.

514. The Ruhmkorff Discharge.—The discharge of the Ruhmkorff coil may be used in many experiments of the kind indicated for frictional and Holtz machines and the Leyden jar, but it gives the most interesting results when made to pass through glass tubes which have been exhausted

[1] This extra current is induced in the successive circles of the primary coil by the breaking of the current in the contiguous parts. When the primary circuit is a straight wire, the extra current is not noticed.

of most of their gaseous contents. In Art. 465 it was stated that the electrical discharge, though taking place with difficulty through ordinary air, takes place quite readily through highly-rarefied air. The same is true for other gases. If a glass tube be filled with air, hydrogen, oxygen, nitrogen, carbonic acid, or any other gas, and then by means of an air-pump most of the gas be taken out, the passage of the Ruhmkorff discharge through the remaining rarefied gas fills the tube with a glow of light. This light is differently colored for different gases. The color in each case is that which is due to the incandescence of that particular gas (Art. 458). The contents of such a tube may thus be accurately determined by discharging an induction-coil through it and examining the discharge with a spectroscope (Art. 302).

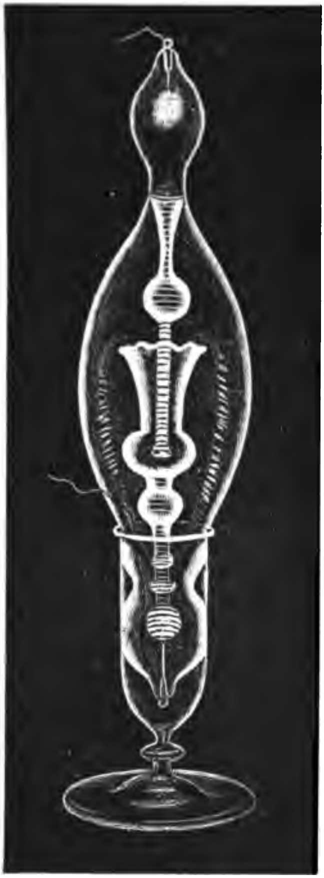


FIG. 292.—GEISSLER TUBE.

515. Geissler Tubes.—Many beautiful designs of such exhausted tubes, *Geissler tubes*, are in the market, and they may generally be made to operate with quite small Ruhmkorff coils. Fig. 292 gives an imperfect idea of the discharge through a Geissler tube in a dark room. The tube is supported by being stood upright in a glass vase. At the two extremities are platinum wires, sealed into the glass and connected with the wires leading from the Ruhmkorff coil. The

glass vase and bulbs inside the tube are colored with oxide of uranium, which possesses in a remarkable degree the power of fluorescence when illuminated by the electric spark. The vase at the bottom is filled with a solution of sulphate of quinine, which exhibits a similar property. The uranium fluorescence should be a light green, the quinine a soft blue. The violet light in the rest of the tube is due to nitrogen or air.

Exercises.—1. Suppose the thread on a common wood-screw to represent a helix and the middle an iron core. With the current running from the point towards the head, which pole of the resulting magnet would the point of the screw represent?

2. How many ohms of resistance in a telegraph-sounder containing 888 feet of copper wire $\frac{1}{16}$ of an inch thick? *Ans.* 12.

3. It is desired to divide an electric current passing between two points into two *equal* parts which shall pass over two iron wires, *a* and *b*. The wire *a* is 100 feet long and $\frac{1}{20}$ of an inch in diameter. The wire *b* is 2500 feet long: what must be its diameter? *Ans.* $\frac{1}{4}$ inch.

4. When telephone-wires are carried on the same poles with telegraph-wires, and parallel with them, the clicks of the telegraph-apparatus are distinctly audible in the telephones: explain this.

5. A small island on the coast of France contains the terminal stations of two ocean telegraph cables. The stations are not connected by wire, but frequently the messages being received or sent by one station may be read at the other: explain this.

V.—RADIANT MATTER.

516. Striæ in Vacuum-Tubes.—In the figure of the Geissler tube it will be noticed that the globular section of violet light near the lowermost (negative) platinum, and also the light in the narrow part of the tube encircled by the vase, exhibit distinct stratifications, or striæ, across the direction of the current. These striæ, or alternate light and dark bands, seem to be occasioned by the motion of the molecules and their impact against one another as they transmit the electric discharge from one to another throughout the length of the tube. If this view is correct, the bright bands are to be considered as caused by the incandescence of the molecules, due to their impact against one another, and the dark bands as sections in which the residual molecules are moving, in the main, parallel to one another, without impact. In other words, a number of molecules occu-

pying a section across the tube (more definite if the tube be of small diameter) carry the discharge a certain part of the length of the tube and there make exchange with the next set, and return to their former position, repeating the operation with very great rapidity, acting as electrified bodies. The fact that the stratifications exist, though very fine, in comparatively dense gases, and increase in width as the exhaustion of the tube becomes more complete, seems to favor this view.

517. **Discoveries of Dr. Crookes.**—In 1879, William Crookes, F.R.S., delivered a lecture before the British Association, in which he announced a new set of phenomena, obtained in tubes exhausted far beyond the point at which the striæ and luminous effects are best shown. With this degree of exhaustion, stratification and all other evidence of the molecules striking against one another cease, and the remaining molecules are simply repelled with great violence from the end of the tube which is connected with the negative pole, and move in straight lines until stopped by the glass of the containing vessel or some other solid placed in their path. Now, as the defined characteristic of gases is an interaction among the molecules by which they are constantly repelling one another, and as in these exhausted spaces the remaining molecules seem to move independently of one another, and thus violate the fundamental law of the gaseous condition of matter, Professor Crookes has proposed for the highly-rarefied residue obtained in his tubes the name radiant matter. In general, the exhaustion of the radiant-matter tubes may be said to be $\frac{1}{1,000,000}$ of an atmosphere, or till they contain but that fraction of the air or other gas which they originally contained. Brilliant Geissler-tube phenomena are shown with tubes containing nearly 3000 times as much gas, or about $\frac{1}{350}$ of an atmosphere.

518. **Radiant Matter repelled from a Negative Electrode.**—The properties of radiant matter are best studied by means of the

discharge of an induction-coil. The molecules are repelled from the *negative* pole, indicating that in their natural condition they are in a negatively electrified state.[1] When the negative pole is made in the shape of a plate with considerable surface, they are repelled from the surface at right angles to it, otherwise they take the general direction indicated by the entrance of the negative wire.

519. **Phosphorescence produced by Radiant Matter.**—The particles of radiant matter produce a bright phosphorescence where they strike. Fig. 293 shows the form of a tube with which this is

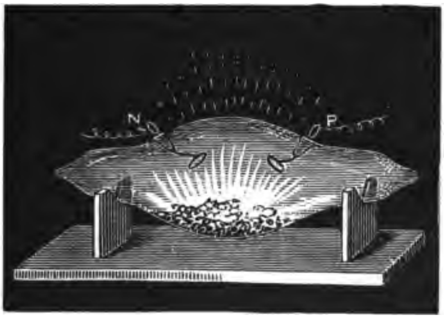


FIG. 293.—SHELL TUBE.

beautifully illustrated. Before being exhausted, the tube has had a collection of rubies, shells, etc., placed in it. On passing the discharge by means of the wires shown, the mineral collection exhibits in the dark a rich glow of mixed colors and no inconsiderable amount of light.

520. **Radiant and Gaseous Matter compared.**—In Fig. 294 are two bulbs which show in a striking manner the difference between radiant and gaseous matter. The bulb B contains radiant matter. The bulb A is an ordinary vacuum-tube containing about 3000 times as many molecules of the original air as B does. In other respects they are entirely similar. Each has a concave aluminum plate, *a* and *a′*, fastened to the sealed-in platinum wire for the negative electrode. Each has three other sealed-in platinum wires, *b*, *c*, *d*, either of which may be made the positive electrode. The negative pole of the Ruhmkorff being connected with *a* in the tube

[1] It might be remarked that the only substances which can be reduced to the condition of radiant matter are those elements which have long been known as the non-metallic or electro-negative elements.

A, the line of light indicating the path of the current extends in a tolerably direct course to that platinum wire which, for the time being, is made the positive pole, whether that be at the opposite side,

FIG. 294.—GEISSLER TUBE AND RADIANT-MATTER TUBE.

the top, or the bottom of the bulb. When, however, the plate *a′* in the bulb B is made the negative pole, the particles are driven across the tube, as indicated in the figure, whether the positive pole be at *b*, *c*, or *d*, or whether it be detached entirely. The point between *c* and *b*, where the molecules strike the glass, is indicated by a bright phosphorescent patch. With a strong coil this spot soon becomes white-hot, and the glass actually melts. No such result is obtainable with ordinary vacuum-tubes.

521. **The "Shadow Tube."**—The glass of which most of these tubes is composed is soft German glass, which yields a bright apple-

green phosphorescence on being bombarded by the particles of radiant matter. Fig. 295 represents a device for showing that the phosphorescence is due to this impact of the molecules.

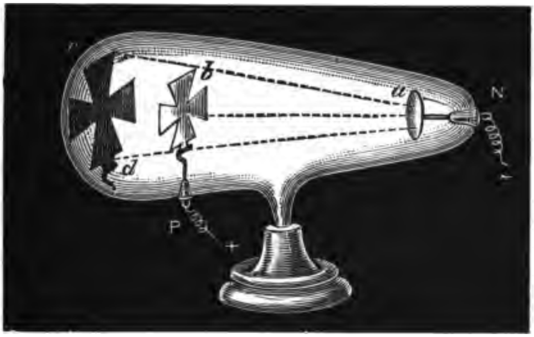


FIG. 295.—THE SHADOW TUBE.

The negative pole *a* is a flat disk, which throws the molecules towards the larger end of the tube. A piece of metallic aluminum, *b*, in the form of a cross, is so placed that it intercepts some of the molecules, and the part of the glass thus protected gives no phosphorescence, and remains dark, resembling a shadow.

522. **The "Railway Tube."**—This impact of particles flying from the negative pole is capable of setting light machinery in motion. Fig. 296 represents a light wheel with broad mica paddles, set on a smooth railway in a highly-exhausted tube.

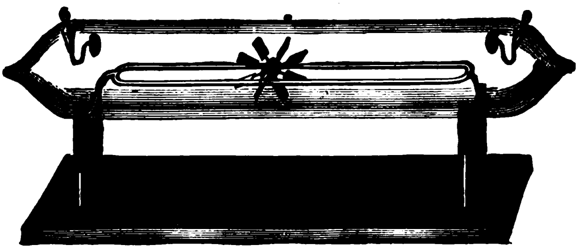


FIG. 296.—THE RAILWAY TUBE.

When the disks at the ends are made the poles of an induction-coil, the wheel rotates rapidly, and travels from the negative towards the positive pole. By reversing the current with the commutator of the Ruhmkorff, the

wheel is driven alternately from end to end of the track as often as desired.

523. **Streams of Radiant Matter self-repellent.**—Fig. 297 represents a piece of apparatus for demonstrating that a stream of radiant matter acts as a line of electrified bodies moving in the same direction, and not as a carrier of an electric current. The disks *a* and *b*, slightly inclined to the vertical, may either be made the negative pole. The positive pole is at *c*. The back of the tube contains a screen of phosphorescent substance, which shows the entire path of the particles which are driven through the slits *d* and *e* of a copper plate. When *b* is made the negative pole, the stream extends from *e* to *f*. When *a* is made the negative pole, the stream extends from *d* to *f*. If *a* and *b* are both made negative poles at the same time, by using two equal wires from the negative pole of the induction-coil, two streams of radiant matter traverse the tube, but they do not converge towards *f*, but move in parallel or divergent lines to *g* and

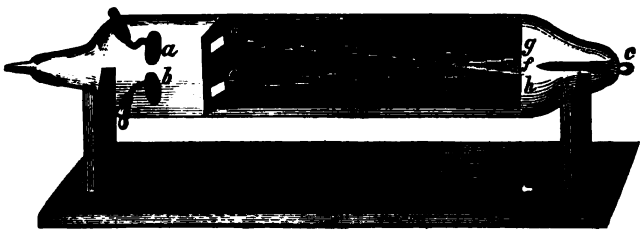


FIG. 297.—TWO STREAMS OF RADIANT MATTER.

h. This shows them to be repellent, and indicates that they are *moving charged bodies* rather than conductors. Parallel *conducting wires* attract each other.

524. Many other instructive and beautiful experiments may be performed with these highly-exhausted vessels. Enough are here given to indicate that the very rare state of matter under examination exhibits properties very different from those of gaseous matter, and that time and further experiments may fully confirm the conclusion that matter exists in four states, as mentioned in Chapter I.,—viz., solid, liquid, gaseous, and radiant.

CHAPTER X.

METEOROLOGY.

525. **Meteorology** treats of the atmosphere and the phenomena there noticeable.[1]

526. **Climate.**—Climate means the conditions of the atmosphere, particularly its states of heat and moisture that exist at any place.

527. **Causes of Climate.**—The causes which affect the climate are principally (1) the distance from the equator, (2) the height above the sea, (3) the distance from the sea, and (4) the prevailing winds.

528. **Latitude of Place.**—It is familiar to all that the nearer a country is to the equator, as a rule, the hotter it is. The reason[2] of this is that the sun shines directly down on the torrid zone, while away from it it shines obliquely and its rays are spread over a great area.

529. **Height above the Sea.**—As we rise above the sea-level, it usually becomes colder. Those who have gone up in balloons speak of the intense cold in the upper regions of the air. The cause of this is that in the rare air the body gives off more heat than it receives. Near the sea-level the dense and moist air serves as a blanket to keep in the heat which the earth receives from the sun. When the sun is shining directly on a mountain it may seem quite

[1] The word is derived from Greek words signifying "the science of things above the earth." It has no special reference to meteors or shooting-stars.

[2] For a fuller explanation, see Sharpless and Philips's Astronomy, p. 92.

warm, for then heat is being taken in; but as soon as a cloud passes over, or the sun sets, the radiation of heat begins, and great cold results. An Alpine traveller has said that the mercury in a black bulb thermometer indicated 132° while in the shade it was only 22°.

Why have a black bulb thermometer?

There is a temporary exception to this rule under certain conditions. On a cold, still morning the thermometer will indicate a lower level in the valleys than on the surrounding hills. This is because the cold air, being heavier, sinks to the lowest level.

530. **Proximity to the Ocean.**—The temperature of a country near the sea varies much less in a year than that of one farther inland.

The cause of this is largely the same as that explained in the preceding paragraph. When the sun's heat-rays fall on land they do not penetrate to any great depth. When the sun sets, or gets low down in winter, the slight amount of heat stored up on the surface of the soil is quickly lost by radiation, and cold weather sets in.

The heat-rays penetrate much more deeply into the water. In clear water it is believed that they affect its temperature to a depth of nearly 600 feet. Water has also great capacity for retaining heat. Hence it stores up large quantities during daytime and in the summer season, and parts with it slowly at night and during the winter. It therefore tends to preserve a more uniform temperature throughout the year, and this affects the climate of the lands bordering on it.

531. **Character of Ground.**—A sandy or stony country, as a desert, becomes quickly heated when exposed to direct rays, and as quickly cools off after they are removed, while a country covered with vegetation retains its heat much longer. Evaporation from the surface of the leaves also uses up some heat, so that a fertile and productive

country has a more equable temperature than a sterile one.

532. **Direction of Winds.**—The direction of the prevailing winds also influences very considerably the character of the climate. The causes which affect the direction of the winds will be explained farther on. Since winds bring the atmosphere of the places which they have traversed, if the prevailing direction in the Northern hemisphere is from the south, the weather will be warm, and if from the north, cold, as compared with that of other countries of the same latitude. If the wind blows in from the sea, the air will be moist, and if from off the land, dry.

As the ocean is more uniform in temperature than the land, winds from off it will be of nearly the same character the year through, while a country, even if near the sea, which is frequently subjected to winds from the interior will vary greatly in climate in the different seasons.

533. **Local Causes.**—There are other causes of climate more local in their character. If a place has a south frontage, so that it is exposed to the more direct rays of the sun, and is shielded from the cold north winds, its average temperature will be higher, and *vice versa.*

Two Arctic localities often differ widely in temperature, from the fact that ice freezes in one and floats away and thaws in the other. Now, freezing always liberates heat from the water, while thawing, requiring heat, abstracts it from the air. The former locality will then be warmer than the latter.

The exposure to the effects of ocean currents also produces a great effect on the climate. Water, as we have seen, has great power to store up heat. If a current of warm water flows against the shore, the heat is largely given out, and the temperature of the *land* is *raised.* The Gulf Stream leaves Florida with a temperature of about 80°. When it completes its circulation and again reaches the torrid zone, its temperature is 40°. These forty degrees of heat have

been given to the land, chiefly Western Europe, thus raising its temperature considerably above that of countries of the same latitude in America.

534. Interference of Causes.—It will thus be seen that a great many causes go to produce the climate of any place. It is often impossible to tell how many of them are in operation. Sometimes they work against one another to produce opposite results. All countries in the torrid zone are not hot, and sometimes we find places at high elevation which are not very cold. But by a careful consideration of the circumstances it can usually be found out how to account for any climate.

THE ATMOSPHERE.

535. Weight of the Atmosphere.—The barometer, as we have seen, indicates the weight of the atmosphere. If it be watched closely, it will be seen to vary slightly through the day. By taking the mean of several readings we get the average height for the day. By taking the mean of these averages for different days we obtain the average for the year. This yearly average differs at different places.

536. Variations.—The average for one month is not the same as that for others. It is usually higher in winter than in summer, and the variation is more marked as we approach the equator. The highest points for the day are about 10 A.M. and 10 P.M., and the lowest six hours from these. The daily fluctuation is also greatest at the equator.

537. Irregular Changes.—But, besides these periodical changes, which are very small, there are irregular ones, which are of much greater consequence and magnitude. It is by them that we are able in some degree to predict the weather. As vapor of water is lighter than air, its admixture with the air causes the mass to become lighter and to produce a fall of the barometer. A fall of the barometer,

then, usually indicates the increase of the amount of moisture in the air, and, as such, is an indication of rain. The words "fair," etc., printed on barometers, mean nothing, because the height of the mercury varies with the locality and other things, and the barometer pointing to "fair" in one place would in another, during exactly the same weather, point to "foul." A sudden descent is generally an indication of an approaching storm, and a sudden rise, of clear weather. But it must be borne in mind that the barometer can indicate a storm only after the moisture is actually in the atmosphere.

538. **Uncertainty of Predictions founded on the Barometer.**—There are so many other causes affecting the height of the barometer besides the moisture in the atmosphere, that meteorologists do not consider that it alone is a safe guide for the prediction of storms. The direction of the winds and the appearances of the clouds must also be taken into account in connection with it, so that, while it is not useless, its heights are not considered in themselves sufficient grounds for predicting the weather. When properly combined with other indications they certainly afford some clue.

539. **Isobaric Lines.**—If the heights of barometers in different parts of the country are observed at exactly the same time, as is done in the signal stations of the United States, and if all the stations which have the same barometric readings are connected by lines, it will usually be found that these are roughly parallel to one another, and frequently are curves enclosing certain territory where the barometer is highest or lowest. These lines are called *isobaric lines.* They change in position rapidly from time to time, and their changes are among the facts relied upon by the head of the Signal Service Bureau to predict the weather. These lines are shown in Fig. 298.

540. **Causes of Changes of Temperature.**—The air becomes heated because (1) it absorbs some of the heat which

passes through it as it comes from the sun; (2) because it absorbs heat which the earth is radiating into space; and (3) because it comes in contact with bodies on the earth

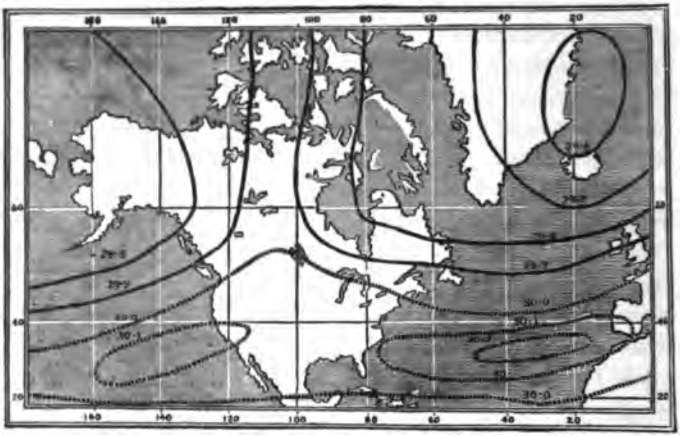


FIG. 298.—ISOBARIC LINES.

which are more or less heated. The second and third of these causes are not subject to any very sudden variations, but the first changes with all the positions of the sun with respect to the observer.

A fourth cause of change of temperature, of less consequence, is the freezing or evaporation of water. When the air is in such a dry state as to cause much evaporation, the change abstracts heat from the air, and cold is produced. When it is already charged with moisture, evaporation ceases. Every one has experienced how much hotter the air feels when moist. This is due to the fact that it does not evaporate the perspiration of the body and so cause coolness. On the other hand, when freezing or condensation is going on, heat is, as it were, squeezed out of the water, and goes into the atmosphere, raising its temperature. This, probably, explains why the Northern hemisphere is, on the average, about three degrees warmer than

the Southern. The great amount of water in the Southern hemisphere makes evaporation, which causes cold.

Clouds at a small height above the earth keep it from losing its heat in space, so that cloudy weather is never the coldest. In a similar way, a sheet or a newspaper put over a plant will protect it in frosty weather by retaining its own warmth and that of the earth.

Our clothing is as much for the purpose of keeping in the heat of the body as of keeping out the cold of winter.

541. **Effect of Clouds.**—"The temperature varies much less over cloudy than over clear districts; it varies less in low than in elevated regions; it is warmer on one side of an area of high or low pressure than on the other, and generally warmer in advance of any storm-centre and colder in the rear."[1]

542. **Hottest and Coldest Months.**—The hottest month in the year is August, and the coldest is January. These do not coincide with the times when the sun is at his position of greatest and least power, which are about the 20th of June and the 20th of December. But for some time after the 20th of December the earth is still radiating heat more rapidly than it is taking it in, and hence continues to grow cooler; and for some time after the 20th of June the earth receives more heat than it radiates, and so continues to grow hotter.

For the same reasons the highest daily temperature occurs, on the average, at 2 P.M., and the lowest at 4 A.M.

543. **Position of Thermometer.**—By the temperature of the atmosphere we mean the temperature in the shade. A thermometer to record this should, therefore, be protected from the direct rays of the sun, and from radiation from walls and other bodies liable to become heated.

544. **Isothermal Lines.**—If all the places on the earth having the same mean annual temperature be joined, these

[1] Circular of the Signal Bureau, U.S.A.

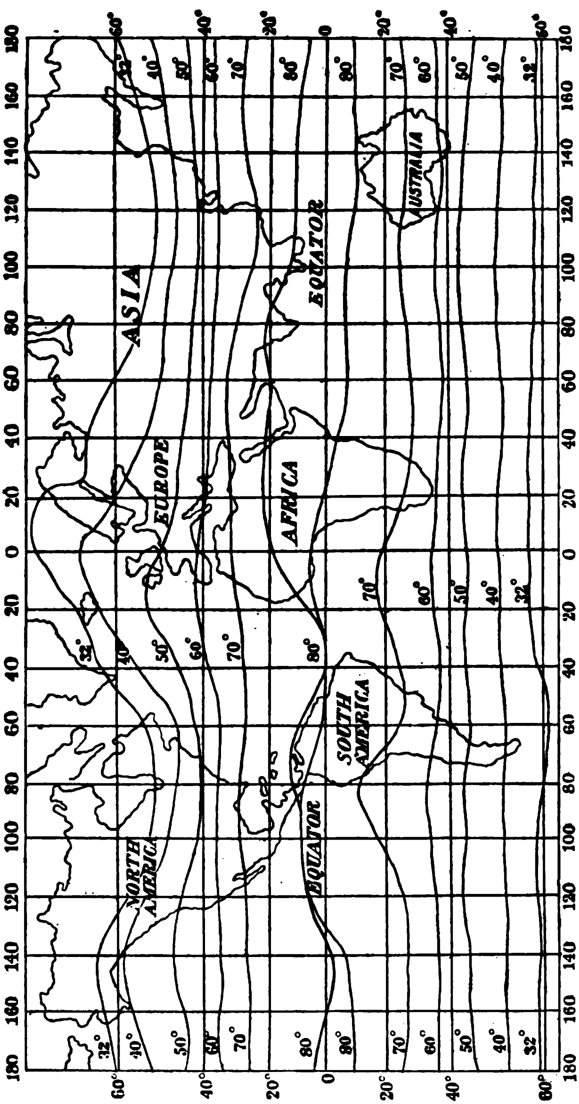


Fig. 299.—Isothermal Lines.

lines are called *isothermal lines.* Roughly speaking, they are parallel with the equator, and agree with parallels of latitude. But local circumstances affect this considerably. Fig. 299 shows the isothermal lines. The figures on them give the mean temperature for the year of all the points through which they pass. It will be observed how the Gulf Stream deflects the lines to the north by raising the temperature of the Atlantic Ocean, and how the warm air from the Pacific raises the temperature of the Western United States.

545. **Moisture in the Atmosphere.**—The air is porous, and particles of vapor of water occupy these pores. When heated, the air expands, and the pores are enlarged, so that more room exists for vapor. When the pores are full of moisture, the air is said to be *saturated.* If the temperature is raised, the same air is not saturated; if it is lowered, some of the moisture is squeezed out, and shows itself as mist, dew, frost, rain, hail, snow, or clouds.

546. **Relative Humidity.**—The capacity of the air to hold water, then, depends on its temperature. The absolute amount of moisture is not measured by meteorologists, only the *percentage of full saturation.* This is called the *relative humidity.* If the air is just half full of moisture, the relative humidity is 50; if full, 100; if absolutely dry, 0; but if, while the amount of moisture remains the same, the temperature is raised, the relative humidity is lowered.

547. **Dew-Point.**—If a certain amount of moisture exists in the atmosphere, the air can be cooled down to such a temperature that it will be saturated. This temperature is the *dew-point.* It is not uniform, but varies with the humidity and temperature of the air. The air is usually not fully saturated with moisture at the temperature which exists. The dew-point in ordinary clear weather is about 10° below the actual temperature, and in exceptionally dry times it is as much as 30° below in this climate. By this we mean that ordinary air must be diminished in temper-

ature 10° before it will be saturated and dew or clouds will begin to form.

548. Hygrometer.—The relative humidity of the air is determined by an instrument called the *hygrometer*.

Experiment 185.—Buy two thermometers and place them side by side. Wrap the bulb of one in a candle-wick, which passes down into a vessel of water so close that the wick around the bulb will always be wet. The "wet-bulb thermometer" will show a lower temperature than the "dry-bulb thermometer," for evaporation from the wick cools the bulb and the mercury in the tube. The amount of this evaporation will depend on the dryness of the air. If it is saturated, there will be no evaporation, and the two thermometers will register the same. If the air is very dry, much evaporation will result, and there will be a great difference. From the readings of the two thermometers it is possible to calculate the absolute amount of moisture in the air, the relative humidity, and the dew-point.

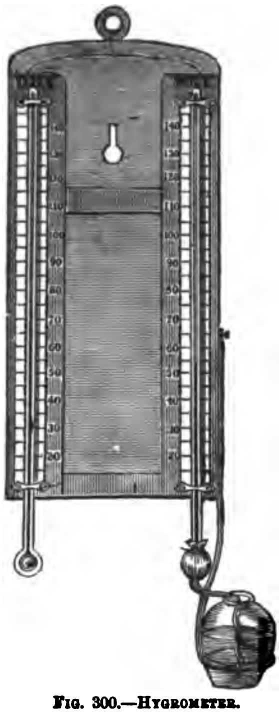


FIG. 300.—HYGROMETER.

549. Variation of Moisture.—The amount of vapor in the atmosphere varies with the time of day, being greatest during the latter part of the afternoon, and least during the latter part of the night. This is due to the evaporation which goes on while the sun is shining, which adds to the moisture in the air through the day, and to the condensation of moisture which results from the lowering of temperature during the night. For similar reasons the amount is greater in summer than in winter. It is also greater near the earth than in the higher regions of the air, though no air has been found entirely free from moisture. Up to a height of from 2000 to 3000 feet there is, however, little, if any, decrease in the humidity.

"There is an increase of moisture near bodies of warm water, fields of snow, extensive forests and meadows, etc., as compared with dry plains and rocky mountains. The humidity will be found large in advance of storm-centres, and small in their rear. It will be greater over warm cloudy districts than where cold and clear weather prevails. Certain winds will be found to be moister than others. The west and northwest are generally the driest in the Mississippi Valley. Dryness will be found attending clearing-up weather. Dampness or a large increase of relative humidity accompanies threatening weather as an almost invariable premonition."[1]

550. **Indian Summer.**—The haziness which is noticed in the atmosphere at certain times, more particularly during "Indian summer," is largely the result of particles of dust or charcoal which come from forest fires, and which possess the property of attracting moisture and thus producing dry weather. A heavy rain will wash this out and leave the air clear.

551. **Dew.**—The foliage of plants, the grass, and all things exposed to the air at night quickly lose their heat. They cool the air in immediate contact with them below the dew-point, and, it being no longer able to hold the vapor, this is deposited on the cold bodies. This is *dew.* A pitcher of ice-water will collect dew on its surface from a similar cause.

A clear night favors the deposition of dew, for when clouds are above the earth they retain the heat, so that the grass is not cooled below the dew-point. A comparatively still night favors it, because in a strong breeze no portion of the atmosphere is long enough in contact with the bodies to be sufficiently cooled. Great relative humidity favors it, for then the dew-point is not much below the ordinary temperature, and but little cooling suffices.

[1] Circular of Signal Bureau, U.S.A.

552. **Frost.**—Frost is frozen vapor or frozen dew. The vapor freezes in the air, and then settles to the ground in the form of little crystals. Hence it is necessary for the temperature to be as low as 32° at the place of freezing in order for frost to be formed. It is often cold enough to make frost in the valleys when the thermometer a little higher up indicates a higher temperature.

553. **Fog.**—When a large mass of air is cooled below the dew-point, all the vapor which it cannot contain becomes visible. When this is near the earth it is called a *fog* or *mist.* This cooling may be the result of a cold wind blowing in from the north on air nearly saturated, or of the presence of a bog or lake, which keeps the air cool at a certain spot. In the latter case the fog is permanent, while its particles may be rapidly changing. As soon as a mass of air blows into this position it is cooled down so as to make its vapor visible, and when it goes out at the other side the temperature is raised so that it hides it again. A fog usually hangs over the banks of Newfoundland, because there the cold and warm currents meet, and the warm air is cooled below the dew-point. It is also seen over rivers, on account of their cooling effect on the air.

554. **Fog, Particles of Liquid.**—Particles of vapor are transparent, and when they lie between the particles of air they do not obstruct the view. When, however, they are not thus placed, they collect in little drops, which float in the air and obstruct the view, because the light-rays are lost by their numerous reflections from one to the other. In the same way glass is transparent, but a vessel filled with broken glass is opaque. In the condensation which occurs when fog is formed, the vapor changes from a gaseous body to a liquid body. The change may be seen at the spout of a tea-kettle. Close to the orifice nothing is seen, for the steam is a transparent gas. When it goes out a little space it is cooled below the dew-point, and liquid vapor of water becomes visible.

555. **Cloud.**—When this condensation goes on in the upper regions of the atmosphere, a *cloud* is formed. A cloud is simply a fog or mist at some elevation above the earth. When we ascend a mountain we often enter a cloud, and no distinction from a mist is noticed. Clouds are apt to hang around mountain-tops, for the cold peaks lower the temperature of the air, and as fast as it rises to pass over them it is cooled below the dew-point. When it descends the opposite side it becomes warm again, and the cloud disappears from view. While the cloud apparently remains fixed in position, its particles are constantly changing.

556. **Causes of Clouds.**—A cloud may also be formed by a cold wind blowing on warmer air, or by warmer air blowing into a colder region, or by an ascending current of air expanding and so causing cold (Art. 367). The latter cause is probably the most common. The vapor formed by the action of the sun upon the waters of the earth tends by its own expansive force to rise above the earth; as it rises it reaches rarer strata of air, and so expands more rapidly. This expansion causes cold, and, besides this, the air itself is colder as we rise higher. The vapor is then changed from invisible vapor to the little particles of water which constitute cloud.

557. **Forms of Clouds.**—As the cloud-particles are heavier than the air, they gradually sink. They would fall to the ground did they not come into warmer air, by which they are again converted into invisible vapor. As soon as they get down to a stratum which raises their temperature above the dew-point, they disappear from view. This explains why certain clouds have flat bases while their tops are heaped up in masses like mountains. This form of cloud has often great thickness. The bottom may not be over a half-mile from the earth, but the top sometimes reaches the height of four miles. In general, the thickness of clouds is not more than a half-mile, and they vary from a half-mile to five miles above the surface of the earth.

There is frequently just as much vapor below the cloud as in them, but the warmer temperature prevents it from being seen.

Questions.—When you build a fire in a damp room, do you decrease the amount of moisture in the room? Why is the room drier? Is it the visible or the invisible vapor that gives the idea of dampness?

558. **Classes of Clouds.**—Clouds are usually divided into four main classes,—*cirrus*, *cumulus*, *stratus*, and *nimbus*.

559. **Cirrus.**—The *cirrus* clouds are the light, feathery masses which float in the air, scarcely screening the sun. They are believed to be composed of small particles of ice or snow floating at a great height. They sometimes betoken the coming of a storm, though usually nothing ever falls from them.

560. **Cumulus.**—The *cumulus* or "heap" clouds are clouds which are common in summer-time in fair weather. They are the clouds with flat bases and hemispherical tops, mentioned in Paragraph 557. They are the tops of columns of vapor reaching down to the earth which become visible at a height where the temperature falls below the dew-point. The shapes of these clouds are best seen through a piece of blue glass, which diminishes some of the glare of their light.

561. **Stratus.**—The *stratus* clouds are those which are seen in lines stretched along parallel to the horizon. When overhead, they cover the sky with a cloud of uniform darkness. They are near the earth, and of no great thickness.

562. **Nimbus.**—The *nimbus* are heavy black clouds, from which rain falls.

563. **Mixed Classes.**—There are often observed clouds which partake of the character of two or more kinds; these are named *cirro-stratus*, *cumulo-stratus*, etc.

564. **Disappearance of Clouds.**—Clouds form and disappear in the sky while we are looking at them. The clearing up after a storm is not so much the result of the clouds

blowing away as of their disappearance by being changed to invisible vapor by a drier atmosphere.

565. **Clouds around a Storm.**—"Two or more layers of clouds almost invariably coexist wherever extended rain-storms prevail, the upper layer stretching far in advance of the lower, but stretching down to it where rain is falling most abundantly. In the rear of this area cumulus clouds are abundant. Cumulus and cirrus clouds are not inconsistent with the idea of clear or fair weather. Cirro-stratus almost invariably precede an extensive rain-storm, whether in winter or summer. The stratus will generally be found in connection with threatening weather."[1]

566. **Rain.**—When the air is suddenly cooled below the dew-point, the little particles collect in drops, and rain is formed. This sudden cooling is most readily effected by an upward current, which carries air nearly saturated to a cooler level. There is a difference of about 35° between the air at the surface and the air two miles above the surface of the earth. When the air laden with moisture from the ocean is carried landward and over a mountain-top, we usually have copious rains. Another cause is the mixing of two clouds or two masses of air of different temperatures. If you mix a cubic foot of saturated air at 90° and another at 30° they will have a mean temperature of 60°; but air at this temperature will not hold all the moisture of both masses, and some must fall as rain.

567. **Amount of Rainfall.**—More rain falls at the equator than elsewhere, and the decrease is quite uniform to the poles. About 100 inches of rain fall at the equator annually. By this we mean that if all of it could be collected it would cover the surface to a depth of 100 inches. In our latitude the average rainfall is between 30 and 40 inches.

568. **Snow.**—When the vapor of the air is frozen, snow is formed. Freezing is a form of crystallization, and the

[1] Circular of Signal Bureau, U.S.A.

forms of the crystals of snow are very beautiful. To observe them well, let them fall on cold pieces of colored glass and examine them with a microscope of low power. *Do not breathe on them.*

FIG. 301.—FORMS OF SNOW-CRYSTALS.

Prof. Tyndall speaks of the snow-crystals which he saw on Monte Rosa as "a shower of frozen flowers; all of them were six-leaved; some of the leaves threw out lateral ribs like ferns; some were rounded, others arrowy and serrated; but there was no deviation from the six-leaved type."

569. **Hail.**—Hail is frozen water. It is produced during thunder-storms by the approach of a cold current, which forces upward the warm, saturated air of the lower regions. Snow is first formed, and the whirling action of the air collects this into little balls, which, as they move through the snow and vapor, become alternately coated with snow and covered with ice, gradually but rapidly growing till they reach sometimes the size of turkey-eggs. When examined, the centre is seen to consist of

FIG. 302.—SECTION OF HAIL-STONE.

snow, and often alternate layers of snow and ice may be noticed.

570. **Wind.**—Wind is air in motion. Air having mass, when it strikes any object it presses against it, the pressure being harder the faster it moves. A wind moving at the rate of 4 miles an hour is a pleasant breeze, and presses against every square foot of surface which it strikes vertically with a force of about an ounce. A brisk wind of 25 miles per hour has a force of about 3 pounds per square foot; a very high wind of 45 miles per hour, of 10 pounds per square foot; a hurricane of 80 miles per hour, of 31 pounds per square foot.

The mean velocity of the wind in the Eastern United States is about 10 or 12 miles per hour, being more in winter than in summer, and is greatest at 2 P.M., and least at night. The daily curve is seen in Fig. 303.

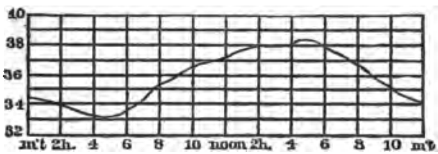


FIG. 303.—DAILY CURVE OF WIND.

571. **Cause of Winds.**—The air at the equator is heated by the direct rays of the sun, and is pushed up by the heavier cold winds from the polar regions settling down to take its place. The heated air moves as an upper current towards the poles, while the cold air moves as a surface-current towards the equator. This interchange would go on regularly and continually were it not for the rotation of the earth on its axis. A particle at the equator moves with greater velocity than one near the poles, because it has so much farther to go in the same time. The air partakes of the motion of the earth below it, and when the slowly-moving air from the higher latitudes sweeps down towards the equator it is left behind and falls back towards

the west. This produces the trade-winds of the torrid zone. When the upper currents from the equator reach the temperate zones they become sufficiently cooled to fall again to the surface, and, having the rapid equatorial motion, they sweep ahead of the earth and form the prevailing westerly winds of our latitude.

The extreme cold of the polar regions produces surface-currents away from the poles and upper currents towards them.

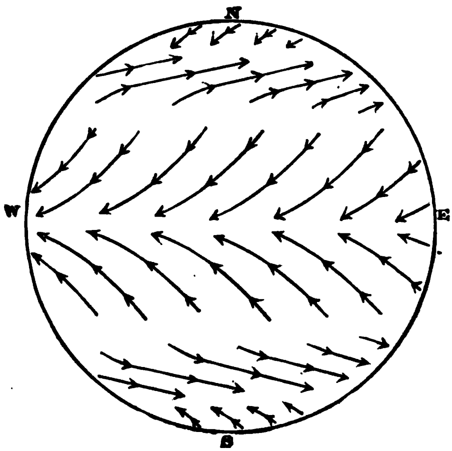


FIG. 304.—WINDS OVER THE GLOBE.

The surface-winds are shown in Fig. 304, and Fig. 305 gives the whole circulation without the effects of the earth's rotation.

572. **Variable Winds.**—These are the general systems of winds. But, as every one knows, the changes in direction and intensity of the wind are almost continuous. There are numerous local circumstances which determine particular winds. Wherever there is low pressure, as indicated by the barometer, there are surface-currents sweeping in from all around, for the equilibrium of the atmosphere is destroyed and a flow sets in to restore it. If any place

becomes greatly heated, the air will tend to flow into it in all directions, producing surface-currents towards, and upper currents away from, the heated place. When the heated air rises, it becomes cooled, spreads out, and falls down, and is returned again to the place whence it came.

The reverse would take place around a cold centre.

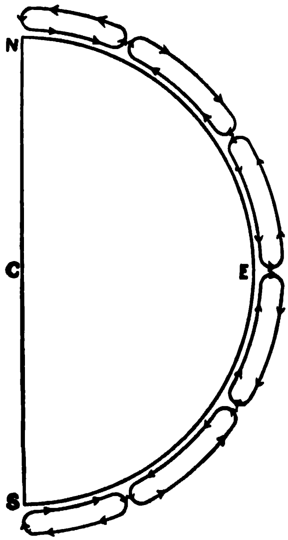


FIG. 305.—CIRCULATION IN THE AIR.

573. **Land and Sea Breezes.**—During the day the land heats up more than the water, so that along the sea-coast there are usually breezes blowing in from the sea during the day. At night it loses its heat more quickly and becomes cooler than the sea, so that the breeze sets in in the opposite direction.

574. **Monsoons.**—The same cause produces the monsoons of the Indian Ocean. The regions of India become heated in their summer, and the wind sets in strongly from the Indian Ocean. In the winter the reverse is the case.

575. **Moisture a Cause of Winds.**—Another local cause of winds is the moisture in the atmosphere. As vapor of water is lighter than air, the sudden formation of cloud will tend to produce a low barometer. Winds will set in towards this centre to restore the equilibrium.

576. **Difficulty in ascertaining the Cause of Winds.**—Among all these causes it is often impossible to say which one is producing the wind at a given time and place. Its fickleness has become proverbial, and many causes doubtless operate together in producing the modifications. The changes are not the result of chance, but every particle of

air moves in obedience to the impulses which act upon it. Winds are great agents for purifying the earth and making it healthy, and a multitude of ways in which they are useful to man will suggest themselves to any one.

577. **Storm.**—A storm is a great commotion in the atmosphere. Rain, hail, or snow generally accompanies it.

578. **Effect of Heat.**—In case of the heating of a large tract, the cold air flows in from all around. The hot air rises and spreads out. This mingling of the currents often produces clouds and rain, as has been explained. This is a storm. The whole system of currents and clouds is then carried by the prevailing winds over the country. A barometer near the centre would show low pressure.

579. **Effect of Rotation of the Earth.**—Were there no rotation of the earth, the surface-air would always blow directly towards the storm-centre, and the upper air away. In the Northern hemisphere the winds coming in from the south are, by their more rapid motion with the earth around its axis, carried towards the east, and those coming in from the north are in like manner deflected towards the west. This makes them approach the centre not directly, but in a spiral curve, and creates a "cyclone." Nearly all our storms are more or less cyclonic in their character. The reverse kind of cyclone exists in the Southern hemisphere.

580. **Movement of Storms.**—The prevailing winds in the torrid zone being easterly, the storm is carried towards the west. As it recedes from the equator it reaches the region of westerly winds, by which it is borne eastward. Most of our large storms come from the west or the southwest.

This may not be the direction of the wind at the time. The wind at any time is usually directed obliquely towards the storm-centre, and this is frequently modified by local causes, so that there are all possible directions inside the storm-area. In the Atlantic States the winds commonly blow from some easterly quarter during a storm.

581. **Storm-Centre.**—In the centre of a storm there is a

calm, and sometimes clear weather. After the centre has passed, the wind shifts to the west, it often rains hard for a short time, and then clears away. When the wind shifts

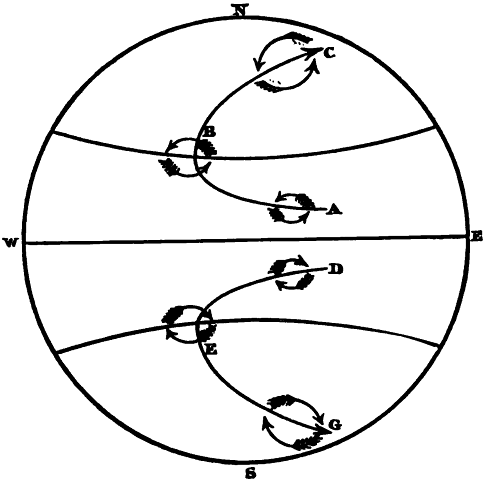


FIG. 306.—MOTION OF STORM-CENTRE AND OF AIR AROUND IT.

to the west after several days of east wind, clear weather soon follows.

582. **Direction of Wind around a Storm-Centre.**—To remember the direction of the surface-winds around a storm-centre, the student may notice that in the Northern hemisphere, to a person situated above, the motion is opposite to that of the hands of a watch.

583. **Direction of Storms.**—The direction of storms through the United States is towards the east, varying sometimes to the northeast or the southeast, and their average hourly rate of motion is 21 miles in summer and 30 in winter. They sometimes move faster than this, and sometimes remain almost stationary.

584. **Thunder-Storms.**—The storms of wind and rain of summer, often accompanied by thunder and lightning, do not move across the continent, but are local in their origin.

The heat of the sun fills the lower regions with vapor over some point, and causes it to ascend till its cooling produces cumulus clouds level at base, heaped up on top. This goes on till condensation into drops ensues and rain falls. The winds sweep the clouds along, and there is a certain amount of cyclonic tendency, but the storm does not extend far, and is soon exhausted. The electric phenomena accompanying such storms have been explained in the chapter on electricity.

585. **Cyclones.**—Frequently cyclones or hurricanes are formed in the Atlantic Ocean, near the equator, and are swept along westward, as shown in Fig. 307, then turn

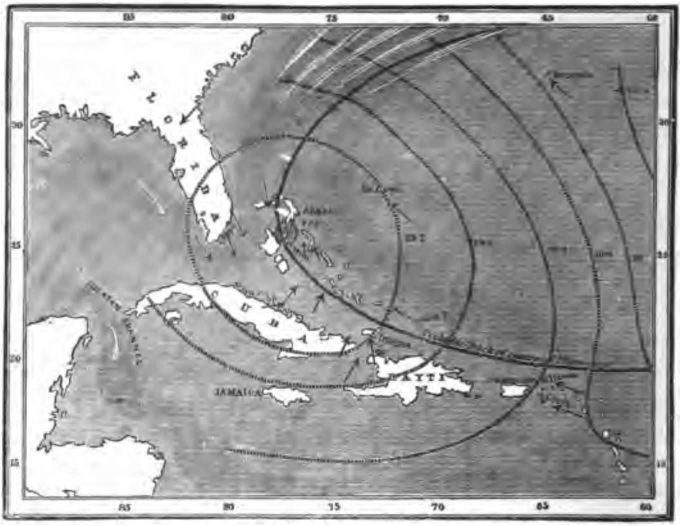


FIG. 307.—COURSE OF CYCLONES IN THE ATLANTIC OCEAN.

opposite the South Atlantic States, and are usually lost in the North Atlantic, though they sometimes doubtless reach Europe. In this case, as the storm-centre sweeps up the course of the Gulf Stream, we have east and southeast winds along our eastern coast, accompanied by heavy rain.

The eastern storms which begin at the South are usually of this class. Occasionally the storm does not turn till it reaches the Gulf of Mexico, when it moves centrally across the United States.

In the equatorial regions the cyclones are more violent, the rain is more extensive, and the wind is stronger than in the temperate zones. The energy is somewhat diminished by the distance travelled.

586. **Prediction of Storms—Signal Bureau.**—The laws governing the motions of storms are now so well established that it is possible to predict with tolerable certainty for one or two days in advance what the weather will be. This is the work of the Signal Service Bureau of the War Department of the United States Government. There are scattered over the country about one hundred stations, at each of which, three times every day, at the same instant of actual time, observations are taken by the officer in charge. These are telegraphed immediately to the chief signal officer at Washington, who in turn telegraphs many of them to some of the more important stations, from which bulletins of the prominent features are issued. These bulletins tell—

Height of the barometer;
Change since last report;
Thermometer;
Change in the last twenty-four hours;
Relative humidity;
Direction of the wind;
Velocity of the wind;
Force of the wind;
Amount of cloud;
Rainfall since last report;
State of the weather.

These bulletins are open to examination at the signal-offices and other public places in the cities and towns to which they are transmitted.

Besides the bulletins, a statement of synopses and indications is prepared at the office of the chief signal officer, and thence issued thrice daily. The press agents telegraph it over the country. This statement is given out at 1 A.M., 10 A.M., and 7 P.M. daily, Washington time.

587. **Correctness of the Indications.**—The indications nearly always prove correct. The signal officer receives reports of storms, or cold waves, or clearing weather, from the West, and their rate of travel, from which he has to predict where they will be at a given time. It is not always a simple matter. He has to take into account a variety of possible modifying circumstances, and great study and experience are needed to make it right in nine cases out of ten, which is about the record of our bureau. No other nation has so complete or well-arranged a system as ours, and it is well worth all it costs. Many vessels are protected from wreck by heeding the signals of a coming storm which are displayed along the coast, and the dwellers along the Western rivers are often saved from floods by timely notice of their approach.

588. **Weather Chart.**—The chief signal officer also issues, thrice daily, a graphic weather chart, which shows at a glance the weather all over the country at that hour. Any one, with proper care and knowledge, can forecast the weather for himself by a study of these charts.

APPENDIX I.

THE METRIC SYSTEM.

THE metric system of weights and measures was devised in France about the beginning of the present century. It is now in general use in most of the countries of the civilized world, and in the others is largely used in scientific work.

The unit of length in this system is the *metre*, which is equivalent to 39.37 inches. This was taken because it is one ten-millionth of the distance from the earth's equator to the pole.[1] On account of its great convenience, the system was made decimal throughout. The prefixes to denote the fractions of a unit are the Latin numerals, and are the same for all the tables, while the Greek numerals indicate the multiples of the unit in all the tables.

TABLE OF MEASURES OF LENGTH.

		SYMBOL.	METRIC VALUE.	U.S. VALUE.
	1 millimetre,	*mm.*	.001 m.	.03937 in.
10 millimetres	= 1 centimetre,	*cm.*	.01 m.	.3937 in.
10 centimetres	= 1 decimetre,	*dm.*	.1 m.	3.937 in.
10 decimetres	= 1 metre,	*m.*	1 m.	39.37 in.
10 metres	= 1 dekametre,	*Dm.*	10 m.	32.81 ft.
10 dekametres	= 1 hectometre,	*Hm.*	100 m.	19.92 rd.
10 hectometres	= 1 kilometre,	*Km.*	1,000 m.	.6214 mi.
10 kilometres	= 1 myriametre,	*Mm.*	10,000 m.	6.214 mi.

The unit of capacity is the *litre* (lee′ter); it is the quantity which a cubical box, 1 decimetre each way inside, will hold. It is equivalent to 1.0567 quarts liquid measure, or .908 quart dry measure, so that it is between our dry and liquid quarts, and does not differ

[1] The more accurate measurements of recent years have shown that the standard metre which the French adopted, and which is still used everywhere, is a trifle ($\frac{1}{5000}$) shorter than an exact ten-millionth of this distance.

greatly from either. The same measures are used for both liquid and dry measure. The table of measures of capacity is exactly the same as the one for length given above, except that *metre* is changed to *litre*. Its symbol is *l*.

The unit of weight is the *gram;* it is the weight of pure water at 39° F. which a cubical box, 1 centimetre each way inside, will hold. It is equivalent to 15.432 grains; a five-cent piece weighs 5 grams and is 2 centimetres in diameter. The table is made in the same way as before, by changing *metre* to *gram*, in the table given above. Its symbol is *g*.

In measuring surfaces the square metre, square dekametre, etc., are used. The *are* (air), which is a square dekametre, is also used, and a table is made by using it with the common prefixes.

Cubic decimetres, cubic metres, etc., are also used in measuring solids, as well as the *stere* (stair), which is a cubic metre. Its table is made in the same way as the others.

APPENDIX II.

A TABLE OF SPECIFIC GRAVITIES.

LIQUIDS.

Pure water, at 39° F.	1.000	Sulphuric Acid	1.841
Sea-water	1.026	Milk	1.032
Alcohol	.791 to .916	Mercury, at 32° F.	13.596
Ether	.716		

SOLIDS.

Iridium	23	Brick	2 to 2.17
Platinum	21 to 22	Chalk	1.8 to 2.8
Gold	19 to 19.6	Coal, bituminous	1.02 to 1.35
Lead	11.4	" anthracite	1.36 to 1.85
Silver	10.5	Limestone	2.4 to 3.
Copper	8.6 to 8.9	Ice	.93
Brass	7.8 to 8.5	Wood, lignum-vitæ	1.34
Iron, cast	7 to 7.3	" hickory	.83 to 1.
" wrought	7.6 to 7.8	" oak	.85
Steel	7.8	" pine	.42 to .55
Glass	2.5 to 3	" cork	.24
Quartz	2.65		

GASES.

Air	1.	Hydrogen	.07
Oxygen	1.11		

INDEX.

[THE NUMBERS REFER TO PAGES.]

L.

M.

N.

O.

P.

R.

A LIST OF BOOKS

SELECTED FROM THE

Catalogue

—OF—

J. B. LIPPINCOTT COMPANY.

(COMPLETE CATALOGUE SENT ON APPLICATION.)